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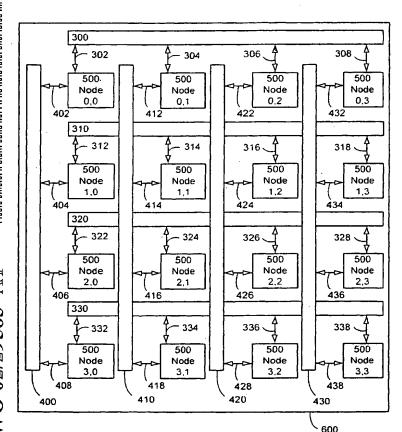
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(54) Title: SYSTEM, METHOD, AND NODE OF A MULTI-DIMENSIONAL PLEX COMMUNICATION NETWORK AND NODE THEREOF

(57) Abstract: A method of communicating is discloses and a communications network (600) having M orthogonal directions that supports communications between an M dimensional lattice of nodes, where M is at least two with greater communication performance than mesh or toroidal communications schemes and lower system complexity than either direct interconnect or switch interconnect schemes.

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SYSTEM, METHOD, AND NODE OF A MULTI-DIMENSIONAL
PLEX COMMUNICATION NETWORK AND NODE THEREOF

Technical field

5   This invention relates to concurrent high-speed communication networks
acting with multi-dimensional arrays of communications processors and nodes
of such networks.

Background Art

10   Processors have long been coupled in various network configurations to
enhance processing speed, processing power and processor
intercommunication. Many such coupling arrangements sacrifice speed as the
number of nodes of the processor network increases in size.   Other
arrangements couple all or nearly all nodes of the processor network to one
15   another increasing speed at the expense of each node requiring substantial
hardware and management expense.   Still further prior art arrangements
employ high speed switches interconnecting all network nodes to each other.
The switches themselves become complex entities as the number of network
nodes increase. Details of these prior art arrangements are discussed in the
20   following section.

Figure **1A** depicts two processors **100** and **110** coupled **106** to each other,
each with accessibly coupled **102** and **112** memories **104** and **114**,
respectively, as found in the prior art.

I

Systems such as this can be found in many prior art settings. They are so common that the Windows NT™ operating system supports them. Many such operating systems allocate high-speed communication to one processor and use the other processor for more computationally intensive tasks, such as image processing algorithms. Operating systems often provide real-time event-driven software tools to aid in the control of such computing systems. Operating systems often further provide real-time event-driven software tools supporting message passing to organize communication between concurrent tasks or objects, which may reside in different processors.

Processor **100** is accessibly coupled **102** to memory **104**. Processor **110** is accessibly coupled **112** to memory **114**. Processor **100** is communicatively coupled **106** to processor **110**. Processor **110** is further coupled **116** with an external communications network.

Typically, processor **110** takes care of the large IO overhead tasks, such as communicating **116** with a high-speed network. Processor **100** is often allocated to perform one or more large local computational tasks, as often found in graphics development, signal processing, and image processing applications.

Note that in many situations, each processor would be seen as a node in the communications scheme. In many other situations, the combination of the two processors would be seen as a node in a larger computing network.

Figure **1B** depicts a communication scheme through a square array of 16 nodes, as found in the prior art.

2

Consider the transfer of a message from one node to another node. The communication performance is often measured in terms of hops. A hop can be seen as the number of arrows encountered when going from the first node to the second node. Such communication schemes have the problem of

5   requiring a very large number of hops to communicate between certain nodes. In this scheme, the number of hops can be half the total number of nodes in the communication scheme. In Figure 1B, assume N=4 nodes in each of the two orthogonal directions (up-down and left-right). The maximum number of hops is half the total number of nodes, or $(N^2)/2$ hops or 8 hops.

10   Figure 1C depicts a two-dimensional communications mesh architecture coupled with the two-dimensional node array of 4 rows and 4 columns of Figure 1B, as found in the prior art.

Note that as used herein, N will refer to the number of nodes in each orthogonal direction, or side of a multi-dimensional array of nodes. The

15   dimensionality of the array will be referred to as M. When a node array is not uniform in each orthogonal direction, it will be specifically noted.

Figure 1C depicts a nearest neighbor communications scheme based around a two dimensional rectangular grid arrangement of nodes **200**. This has been extensively researched and applied in a variety of large scale applications

20   since at least the 1980's.

The great strength of this scheme is that it provides an interconnect mechanism which is a big improvement over connecting the same number of processors in a the communication of Figure 1B, while requiring only a relatively small number of interconnects.

3

The maximum number of hops necessary to communicate between two arbitrarily selected nodes is the sum of the arrows on the sides of the array, or $2^*(N-1)$. The scheme requires more hops as either the number of rows or columns increase, albeit at a better rate than the communication scheme of

5   Figure 1B.

Figure 2A depicts a two-dimensional, 2-D, toroidal mesh communications architecture of three rows and three columns, as found in the prior art.

A 2-D mesh as shown in Figure 1C can be viewed as residing on a 2-D surface of a piece of paper.

10   Figure 2B depicts the prior art two-dimensional, 2-D, toroidal mesh communications architecture of three rows and three columns shown in Figure 2A but drawn on a torus.

A 2-D toroidal mesh is viewed as residing on the surface of a torus, formed by connecting the left side and right side and then connecting the top side and

15   bottom side, of a 2-D mesh as shown in Figure 2B. The advantage of the toroidal architecture is that it reduces the longest travel time through the communication network to about half that of the 2-D mesh travel time in terms of hops.

3-D toroidal mesh architectures have the same basic properties, although

20   they are much more difficult to visualize. They assume a 3-D locally rectangular lattice of neighboring nodes, but are much more difficult to visualize.

4

In a 2-D toroidal scheme, the communications paths are inherently planar, and in cases above three nodes to a row or column, do not provide complete interconnect between the nodes of a row or column. In point of fact, they teach a locally planar connection grid which, above three nodes in each

5 orthogonal direction, do not form a complete interconnect between the nodes of any orthogonal direction. What is desired is a communications scheme overcoming the limitations of the existing nearest neighbor multi-dimensional communications schemes when N is larger than three. Several schemes have evolved to this end.

10 Figure **2C** depicts eight nodes with a total interconnect communications grid, with every node directly coupled to each of the other nodes, as found in the prior art. Note that each of these nodes must have seven ports to support the communications scheme. So for N^2 nodes in a square configuration, where N is 2 or larger, each node would need N^2-1 ports. This is a serious

15 complexity burden not only on the port hardware at the node, but also in terms of communications management needed at each node to control port communications. This can be a major problem. What is further desired is a communications scheme, which does not place such severe requirements on each node, but supports nearly the same communication performance.

20 Figure **3A** depicts eight nodes communicating directly with a switch **290** and through the switch, each node is directly coupled to each of the other nodes by means of two hops, as found in the prior art.

These systems provide a communication path from each node to any other node in just two hops, one to the switch from the source node and a second

25 from the switch to the destination node. Such interconnect schemes are often

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chosen today. They provide fast interconnect, but the complexity of the communication switching rapidly dwarfs the complexity of the rest of the system as the number of nodes increase.

Communication protocol switches today tend to be either Ethernet to Ethernet

5   switch architectures or Ethernet to ATM back to Ethernet switch architectures. The first is often a circuit switched approach, sometimes involving cross bar switches. The second is a packet switch approach, using asynchronous traversal of the ATM network to wormhole packets from their source to their destinations. These switches are inherently complex. This complexity has

10   negative impact on the initial cost, maintenance, and reliability of such switches and their systems.

Consider the common communications scheme of a 64 port Ethernet switch interconnecting 64 nodes. Such switches are extremely complex. The switch complexity is far greater than the rest of the system taken as a whole. The

15   switch complexity dominates the cost, maintenance and reliability of everything else in such systems. What is further desired is a fast, minimal overhead, lower cost, communications scheme which provides nearly the same performance in terms of hops, but at a fraction of the complexity of the system as a whole.

20   Figure 3B depicts a four dimensional hypercube of 2^4 nodes as found in the prior art.

In this example, M, the dimension of the array, is four and N, the number of nodes in an orthogonal direction, is two. Each of the nodes has M=4 ports. A communication between nodes can take up to M hops. The total

6

interconnects of the system is $(M^*N^{\wedge}M)/2$, which rapidly exceeds the number of processors. This interconnect scheme is a nearest orthogonal neighbor scheme, which when N is larger than two, shares the same problems as the mesh architectures.

5   The hypercube interconnect architecture points to a basic trend in the parallel processor community, the necessity of rewriting major software programs into specialized parallel processor programs. These rewritten parallel processor programs distribute the data processing to be performed over many processing units, which then must communicate their computational results or
10   decisions to at least some other of the processors.

There are numerous schemes for controlling these activities within a node, Single Instruction Multiple Datapath (SIMD), and Multiple Instruction Multiple Datapath (MIMD) are just two approaches. SIMD architectures concurrently act on a single instruction across multiple datapaths. MIMD architectures
15   concurrently act on multiple instructions across multiple datapaths. Note that Single Instruction Single Datapath (SISD) architectures act on a single instruction across one datapath and include microprocessors. Multiple Instruction Single Datapath (MISD) architectures concurrently act on multiple instructions across a single datapath and include MPEG stream decoders.

20   Almost all programs are initially written for SISD architectures. Rewriting major programs for data processing on these various alternative parallel processor architectures often requires reinventing the underlying algorithms of those programs in a concurrent form for the various control and communications schemes.

By way of example, people providing single processor weather prediction or air-frame simulations have built computational tools often at the conceptual limits of comprehension and verification. Such tools do not translate readily into these alternative computer architectures and usually require great effort

5   just to get the algorithms to run in these new environments, much less improve their results. What is further desired is a communication scheme to enable many processors to support major computational problems with existing software, while requiring only minor software conversion.

Figure **3C** depicts the use of two optical fibers to create a bidirectional

10 communications physical transport directly connecting through taps to each of the nodes through a control point as taught by the prior art multiplexing multiple signals into a single physical transport.

This use of fiber optics can be found in Figure **8** and its discussion in U.S. Patents 5,029,962 and 5,037,170. This use of fiber optics can be found in

15 Figure **4** and its discussion in U.S. Patent 4,938,008. This use of fiber optics can be found in Figure **3** and its discussion in U.S. Patent 4,889,403. This use of fiber optics can be found in Figure **1** and its discussion in U.S. Patent 4,815,805. This use of fiber optics can be found in Figures **4, 76-78** and its discussion in U.S. Patent 4,768,854. Note that this patent discusses use of a

20 third optical fiber. This use of fiber optics can be found in Figure **8** and its discussion in U.S. Patents 4,741,585 and 4,824,199.

It is common in the above-cited prior art to discuss the control point as a "headend" which distinguishes the signals received from the nodes using a photocell generating an electrical signal. The electrical signal is tested for a

25 "1" or a "0" condition.

Figure 3D depicts the use of one optical fiber to create a bidirectional communications physical transport directly connecting through taps to each of the nodes through a control point as taught by the prior art multiplexing multiple signals into a single physical transport.

5   This use of fiber optics can be found in Figure 3 and its discussion in U.S. Patents 4,822,125 and 4,557,550.

Figure 3E depicts the use of one optical fiber to create a uni-directional communications physical transport directly connecting through taps to each of the nodes through a control point as taught by the prior art distributing a

10   collection of multiple signals into a single physical transport for multiple destinations.

This use of fiber optics can be found in Figure 5 and its discussion in U.S. Patents 4,747,652 and 4,834,482.

Figures 3C, 3D and 3E have been shown to present various prior art methods

15   employing the physical transport of one or more optical fibers to multiplex and/or distribute multiple communications between multiple points.

To summarize the shortcomings of the prior art, what is needed is a communications scheme supporting nearly the same communication performance while placing much less severe requirements on each node than

20   the complete direct interconnect approach. What is also needed is a fast, minimal efficient communications scheme providing performance similar to the ideal switch interconnect approach, but at a fraction of the complexity of the system as a whole.

Summary of the Invention

Certain embodiments of the invention advantageously provide communications performance similar to the switch interconnect approach, and nearly the same communications performance as the complete direct

5   interconnect approach but at dramatically reduced complexity compared to other known approaches having similar communications performance.

The communications network has M orthogonal directions that support communications between an M dimensional lattice of up to N^M nodes, where M is at least two and N is at least four. Each node pencil in a first orthogonal

10   direction contains at least four nodes and each node pencil in a second orthogonal direction contains at least two nodes. Each of the nodes contains a multiplicity of ports.

As used herein, a node pencil refers to a 1-dimensional collection of nodes differing from each other in only one dimensional component, i.e. the

15   orthogonal direction of the pencil. By way of example, a nodal pencil in the first orthogonal direction of a two-dimensional array contains the nodes differing in only the first dimensional component. A nodal pencil in the second orthogonal direction of a two-dimensional array contains the nodes differing in only the second dimensional component. Node(a,b) will refer to a node in the

20   a location in the first orthogonal direction and b location in the second orthogonal direction.

The communications network is comprised of a communication grid interconnecting the nodes. The communications grid includes up to $N^{(M-1)}$ communication pencils, for each of the M directions. Each of the

communication pencils in each orthogonal direction corresponds to a node pencil containing a multiplicity of nodes, and couples every pairing of nodes of the node pencil directly.

5   As used herein, communication between two nodes of a nodal pencil coupled with the corresponding communication pencil comprises traversal of the physical transport layer(s) of the communication pencil.

Such embodiments of the invention advantageously support direct communication between any two nodes belonging to the same communication pencil, supporting communication between any two nodes in

10   an M dimensional array in at most M hops.

Comparing the invention to existing, prior art direct connection of all nodes finds the following. Direct connection of all nodes provides communication between nodes in one hop, but requires each node have almost as many ports as there are nodes in the array. Each of these ports adds complexity

15   not only to node hardware, but also to the node-resident management of the node's port communication.

Each node pencil in the second orthogonal direction may contain at least three nodes. Each node pencil in the second orthogonal direction may contain at least four nodes.

20   Communication between nodes utilizing a communications switch, provides communication between nodes in two hops, but finds the communication switch complexity rapidly dominating the entire system, adversely affecting initial capital expenditure and maintenance of the system. The reliability of such systems is jeopardized, in that if the switch fails, the system fails.

Each of the communication pencils may be comprised of the number of communications paths required to interconnect each node of the corresponding node pencil directly to the other nodes of the corresponding node pencil. Such embodiments of the invention advantageously support

5   communications paths along each communication pencil based upon point-to-point physical transport layers of various wireline structures, such as wire, fiber optics, twisted pair, coaxial cable, wave-guides such as micro-channel and free space lasers. Free space lasers essentially operate without a physical wireline, but are fundamentally directed through fee space in a

10   fashion closer to wireline than wireless physical transports. They will for the sake of clarity of discourse be considered a wireline physical transport herein. Communication path support may further include, but is not limited to, Wavelength Division Multiplexing (WDM). Communication pencils may advantageously support Ethernet, ArcNet, Token Ring, FDDI and ATM as link

15   layers. The communication gird may advantageously support network layers including, but not limited to, TCP/IP, Netware IPX, SMB and DecNet.

Note that, if a node fails in the communication grid, communication between any pair nodes not including the failed node occurs at almost the same efficiency.

20   If a coupling of a node to a communication pencil fails, or if a communication path between two nodes fails in one communication pencil, the system can route communication between any two nodes through different pencils such that communications performance is not lost. In the same way, if one node fails, the communication between two functioning nodes is at most M hops by

25   rerouting communication through functioning nodes.

Certain embodiments of the invention include communicating between a first node and a second node. The first node is coupled to a first communication pencil coupled to a third node. The third node is coupled a second communication pencil coupled to the second node. Each of the

5   communication pencils includes at least one physical transport layer.

Communicating between the first node and second node includes the following. The first node communicates with the third node via the first communication pencil by traversing all of the physical transport layers included in the first communication pencil. The third node communicates with

10   the second node via the second communication pencil by traversing all of the physical transport layers included in the second communication pencil.

Such embodiments advantageously support extremely high speed communication through the communication pencils, traversing the physical transport layers and using intermediate third nodes, when direct

15   communication between the first node and second node is either excessively costly or infeasible for other reasons.

Certain embodiments of the invention include a node coupling to M communication pencils, where M is at least two. The node includes M communication interfaces, each of the communication interfaces coupling to a

20   corresponding communication pencil. The node support a communication process performed within the node controlling all of the communications interfaces. The communication process includes interacting within the node with the communication interface, for each of the communication interfaces.

Each of these interactions within the node further include the following. Receiving a first communication from the communication interface to create a received communication from the communication interface. Processing the received communication from the communication interface. And sending a

5   local communication to the communication interface to create a second communication to the communication interface.

Such embodiments advantageously support interactive communication control within the node controlling the communication interfaces to each communication pencil coupled to the node.

10   Note that an appendix listing a C programming language model of an embodiment of the invention is attached to this document. It will be apparent to one of skill in the art that this model shows decisions being weighed regarding communicating within a node, communicating external to a node, communicating through the node to other communication interfaces,

15   communicating through the communication interfaces to communicate to elements within the node, communicating through tunnel interfaces, communicating through one or more communication processor coupling mechanism, communicating based upon avoidance of obstructions and communicating based upon various cost factors. Obstructions may include,

20   but are not limited to, various systems failures, omitted elements, network management allocations including but not limited to network partitioning, database access privileges, and network access privileges. Cost factors may include but are not limited to overall communication delay, speed, bandwidth utilization and node resource utilization. Note that obstructions may be

25   expressed as cost factor with exorbitant costs.

Note that the appendix is a working simulation of an embodiment of the invention, and as such, represents an actual reduction to practice of the invention. The model presented in the appendix is just one of many embodiments and has been included to meet in part the duty of candor and
5   demonstrate the details of that implementation. This appendix and the embodiment it models are in no way meant to limit the scope of the claims.

These and other advantages of the present invention will become apparent upon reading the following detailed descriptions and studying the various figures of the drawings.

10

Brief Description of the Drawings

Figure **1A** depicts two processors coupled to each other, each with accessibly coupled memories as found in the prior art;

Figure **1B** depicts a communication scheme through a square array of 16
15   nodes, as found in the prior art;

Figure **1C** depicts a two-dimensional communications mesh architecture coupled with the two-dimensional node array of 4rows and 4 columns of Figure **1B**, as found in the prior art;

Figure **2A** depicts a two-dimensional, 2-D, toroidal mesh communications
20   architecture of three rows and three columns, as found in the prior art;

Figure 2B depicts the prior art two-dimensional, 2-D, toroidal mesh communications architecture of three rows and three columns shown in Figure 2A but drawn on a torus;

Figure 2C depicts eight nodes with a total interconnect communications grid, with every node directly coupled to each of the other nodes, as found in the prior art;

Figure 3A depicts eight nodes communicating directly with a switch **290** and through the switch, each node is directly coupled to each of the other nodes by means of two hops, as found in the prior art;

Figure 3B depicts a four dimensional hypercube of 2^4 nodes as found in the prior art;

Figure 3C depicts the use of two optical fibers to create a bidirectional communications physical transport directly connecting through taps to each of the nodes through a control point as taught by the prior art multiplexing multiple signals into a single physical transport;

Figure 3D depicts the use of one optical fiber to create a bidirectional communications physical transport directly connecting through taps to each of the nodes through a control point as taught by the prior art multiplexing multiple signals into a single physical transport;

Figure 3E depicts the use of one optical fiber to create a uni-directional communications physical transport directly connecting through taps to each of the nodes through a control point as taught by the prior art distributing a

16

collection of multiple signals into a single physical transport for multiple destinations;

Figure **4A** depicts a system **600** including a two-dimensional plex communication grid comprised of communication pencils **400, 410, 420** and

5   **430** in the first orthogonal direction and communication pencils **300, 310, 320** and **330** in the second orthogonal direction, each with N=4 nodes **500**, in accordance with certain embodiments;

Figure **4B** depicts the system **600** including the two-dimensional plex communication grid of Figure **4A** with highlighted communication pencils **400,**

10   **410, 420** and **430** in the first orthogonal direction;

Figure **4C** depicts the system **600** including the two-dimensional plex communication grid of Figure **4A** with highlighted communication pencils **300, 310, 320** and **330** in the second orthogonal direction;

Figure **4D** depicts a system **600** including a two-dimensional plex

15   communication grid with N=4 nodes **500**, each node **500** containing six ports in accordance with certain embodiments of the invention;

Figure **5** depicts a system **600** including a two-dimensional plex communication grid with N=4 nodes **500**, each node containing six ports, two communications processors, each coupled to three ports in accordance with

20   certain embodiments of the invention;

Figure **6** depicts the two communications pencils **410** and **320** coupled to Node 2,1 (**500**) and the two node pencils of Node 2,1 of Figure **4D** in accordance with certain embodiments of the invention;

Figure **7** depicts the communications pencils and their coupling to the node pencils in the first orthogonal direction of the two-dimensional plex communications grid of Figure **4D** in accordance with certain embodiments of the invention;

5   Figure **8** depicts the communications pencils and their coupling to the node pencils in the second orthogonal direction of the two-dimensional plex communications grid of Figure **4D** in accordance with certain embodiments of the invention;

Figure **9** depicts the communications pencils **410** and **320** coupled to Node

10   2,1 (**500**) highlighting communication pencil **410** in the first orthogonal direction of Figures **4D** and **6**;

Figure **10** depicts the communications pencils **410** and **320** coupled to Node 2,1 (**500**) highlighting communication pencil **320** in the second orthogonal direction of Figures **4D** and **6**;

15   Figure **11** depicts the communications pencils **410** and **320** coupled to Node 2,1 (**500**) highlighting the node pencil in the first orthogonal direction of Figures **4D** and **6**;

Figure **12** depicts the communications pencils **410** and **320** coupled to Node 2,1 (**500**) highlighting the node pencil in the second orthogonal direction of

20   Figures **4D** and **6**;

Figure **13A** depicts the difference between the embodiments of the invention depicted in Figure **4D** of a 2-D, N=4 plex communications grid and the

communications grid of a 2-D toroidal mesh interconnecting an N by N grid of nodes as shown in Figure 1C;

Figure 13B depicts a 2-D, N=4 toroidal grid of the prior art mapped onto a torus, in a fashion similar to Figure 2B;

5   Figure 13C depicts the difference between the embodiments of the invention depicted in Figure 4D of a 2-D, N=4 plex communications grid and the communications grid of a 2-D toroidal mesh interconnecting an N by N grid of nodes as shown in Figure 13B;

Figure 14 depicts a system 700 including a three-dimensional array of N=5

10   nodes 500 with orthogonal directions 490, 492 and 494 in accordance with the invention;

Figure 15 depicts some of the node pencils and corresponding communications pencils in the first orthogonal direction of a three-dimensional array of 4*5*5 nodes 500 in accordance with certain embodiments of the

15   invention;

Figure 16 depicts some of the node pencils and corresponding communications pencils in the second orthogonal direction of a three-dimensional array of 4*5*5 nodes 500 in accordance with certain embodiments of the invention;

20   Figure 17 depicts some of the node pencils and corresponding communications pencils in the third orthogonal direction of a three-dimensional array of 4*5*5 nodes 500 in accordance with certain embodiments of the invention;

Figure **18A** depicts a node **500** with up to M*(N-1) ports which couple to the communication pencils of the node which intersect at the node in an M-dimensional array in accordance with certain embodiments of the invention;

Figure **18B** depicts a node **500** with up to P CPU's **510, 520, 550** and **560** coupled by **530-536** to the communication pencils of node **500** which intersect at node **500** in an M-dimensional array in accordance with certain embodiments of the invention; and

Figure **19** depicts a node **500** with up to P CPU's **510, 520, 550** and **560** directly coupled by **538-548,** with ports **516, 526, 556** and **566** which couple to the communication pencils of the node pencils intersecting at the node **500** in an M-dimensional array in accordance with certain embodiments of the invention;

Figure **20A** depicts a system **600** containing an M=2, N=4 plex communication grid with 16=N^M nodes **500**, with one node **500** including four communication processing units (CPUs), three nodes **500** including three CPUs, and 12 nodes **500** including two CPUs, where the 3 CPU nodes each are further coupled to external communications networks and each possess a tunneling interface, in accordance with certain embodiments of the invention;

Figure **20B** alternatively depicts a system **600** containing an M=2, N=4 plex communication grid with 16=N^M nodes **500**, with one node **500** including four communication processing units (CPUs), three nodes **500** including three CPUs, and 12 nodes **500** including two CPUs, where the 3 CPU nodes each are further coupled to external communications networks and each possess a tunneling interface, in accordance with certain embodiments of the invention;

Figure **21** depicts a system **800** including two instances of system **600** as depicted in Figures **20A** and **20 B**, referred to as **600-1** and **600-2**, in accordance with certain embodiments of the invention;

Figure **22** partially depicts a toroidal three-dimensional mesh communication
5   grid for an N=3, three dimensional (M=3) array of nodes **500**, each comprising P=2 Communication Processor Units (CPU) which each comprise M=3 ports for the corresponding communication pencils;

Figure **23A** depicts a flowchart of a method communicating between a first node **500** and a second node **500** when the first node **500** and second node
10   **500** are both coupled to communication pencils coupling to a third node **500**, in accordance with certain embodiments of the invention;

Figure **23B** depicts a detail flowchart of operation **1004** of Figure **23A** further performing the first node communicating with the third node via the first communication pencil;

15   Figure **23C** depicts a detail flowchart of operation **1008** of Figure **23A** further performing the third node communicating with the second node via the second communication pencil;

Figure **24A** depicts a detail flowchart of operation **1032** of Figure **23B** further performing traversing the physical transport layers when the first
20   communication pencil includes a first physical transport layer and second physical transport layer;

Figure **24B** depicts a detail flowchart of operation **1052** of Figure **24C** further performing traversing the physical transport layers when the communication

pencil includes a first physical transport layer and second physical transport layer;

Figure **25** depicts a flowchart of a communication process performed within the node **500** controlling all of the M communications interfaces, where M is between 2 and 5, in accordance with certain embodiments of the invention;

Figure **26** depicts a detail flowchart of operation **1304** of Figure **25** further performing interacting within the node with the first communication interface in accordance with certain embodiments of the invention;

Figure **27A** depicts a detail flowchart of operation **1372** of Figure **26** further performing for each of the communication interfaces coupled to the communication processor, receiving the first communication;

Figure **27B** depicts a detail flowchart of operation **1382** of Figure **26** further performing for each of the communication interfaces coupled to the communication processor, processing the received communication;

Figure **27C** depicts a detail flowchart of operation **1392** of Figure **26** further performing for each of the communication interfaces coupled to the communication processor, sending the local communication;

Figure **28A** depicts a detail flowchart of operation **1432** of Figure **27B** further performing processing the received communication in accordance with certain embodiments of the invention;

Figure **28B** depicts an alternative detail flowchart of operation **1432** of Figure **27B** further performing processing the received communication in accordance with certain embodiments of the invention;

Figure 29A depicts a detail flowchart of operation 1512 of Figure 28A further performing determining the received communication destination;

Figure 29B depicts an alternative detail flowchart of operation 1512 of Figure 28A further performing determining the received communication destination in accordance with certain embodiments of the invention;

Figure 30A depicts a detail flowchart of operation 1300 of Figure 25 further performing the communication process within the node;

Figure 30B depicts a detail flowchart of operation 1582 of Figure 29A further performing evaluating the destination component;

Figure 31A depicts a detail flowchart of operation 1522 of Figure 29A further performing routing the received communication for a communication processor coupled to the communication processor coupling mechanism;

Figure 31B depicts a detail flowchart of operation 1522 of Figure 29A further performing for each of the communication processors, routing the received communication;

Figure 31C depicts a detail flowchart of operation 1532 of Figure 28A further performing for each of the communication processors, delivering the received communication;

Figure 32A depicts a detail flowchart of operation 1532 of Figure 28A further performing for each of the communication processors, the step of delivering the received communication;

23

Figure **32B** depicts a detail flowchart of operation **1432** of Figure **27B** further performing processing the received communication from the communication interface coupled to the communication processor;

Figure **33A** depicts a detail flowchart of operation **1712** of Figure **32B** further

5   performing determining based upon the received communication from the communication interface;

Figure **33B** depicts a detail flowchart of operation **1612** of Figure **30A** further performing maintaining the routing table;

Figure **34A** depicts a detail flowchart of operation **1782** of Figure **33B** further

10   performing distributing the new routing table;

Figure **34B** depicts a detail flowchart of operation **1792** of Figure **34A** further performing communicating the new routing table;

Figure **35A** depicts a detail flowchart of operation **1802** of Figure **34A** further performing replacing the routing table;

15   Figure **35B** depicts a detail flowchart of operation **1772** of Figure **33B** further performing generating the new routing table;

Figure **36A** depicts a detail flowchart of operation **1532** of Figure **28A** further performing delivering the received communication;

Figure **36B** depicts a detail flowchart of operation **1532** of Figure **28A** further

20   performing delivering the received communication;

Figure **36C** depicts a detail flowchart of operation **1382** of Figure **26** further performing processing the received communication;

Figure **37A** depicts a detail flowchart of operation **1932** of Figure **36C** further performing assessing the received communication;

Figure **37B** depicts an alternative detail flowchart of operation **1932** of Figure **36C** further performing assessing the received communication; and

5   Figure **38** depicts a communication interface **900** including P1=4 input ports and P2=4 output ports coupled to a communication pencil including optical fibers **902** and **904**, each optical fiber handling one way traffic with optical fiber **902** coupled **940** through optronic amplifier **942** coupling **944** to optical fiber **904**, in accordance with certain embodiments of the invention.

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Detailed Description of the Invention

Figure **4A** depicts a system **600** including a two-dimensional plex communication grid comprised of communication pencils **400, 410, 420** and **430** in the first orthogonal direction and communication pencils **300, 310, 320**

15   and **330** in the second orthogonal direction, each with N=4 nodes **500**, in accordance with certain embodiments of the invention.

Note that M is two, the dimension of the array of nodes. N is four and each row and column, or node pencil in either of the two orthogonal directions, has 4 nodes.

20   The communications network is comprised of a communication grid interconnecting the nodes. The communications grid includes up to $N^{(M-1)}$, or 4 communication pencils, for each of the M=2 orthogonal directions. Each of the communication pencils in each orthogonal direction is coupled with a

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corresponding node pencil containing a multiplicity of nodes coupling every pairing of nodes of the corresponding node pencil directly.

Communication between two nodes **500** of a nodal pencil coupled with the corresponding communication pencil includes traversal of the physical

5   transport layer(s) of the communication pencil. Such embodiments of the invention advantageously support communications paths along each communication pencil based upon point-to-point physical transport layers, such as fiber optics, microwave wave guides such as micro-channel, and free space lasers. Further embodiments of the invention support Wavelength

10   Division Multiplex (WDM) through the physical transport of the communication paths of the communication pencils.

These communications pencils advantageously support communications paths based upon point-to-point physical transport layers of various wireline structures, such as wire, fiber optics, twisted pair, coaxial cable, wave-guides

15   such as micro-channel and free space lasers. Communication path support may include, but is not limited to, Wavelength Division Multiplexing (WDM). Communication pencils may advantageously support Ethernet, ArcNet, Token Ring, FDDI and ATM as link layers. The communication gird may advantageously support network layers including, but not limited to, TCP/IP,

20   Netware IPX, SMB and DecNet.

Figure **4B** depicts the two-dimensional plex communication grid of Figure **4A** with highlighted communication pencils **400**, **410**, **420** and **430** in the first orthogonal direction. Recall that a nodal pencil in the first orthogonal direction of a two-dimensional array contains the nodes **500** differing in only the first

25   dimensional component.

Consider the node pencil in the first orthogonal direction containing Node 0,0, Node 1,0, Node 2,0 and Node 3,0. The communication pencil 400 in the first orthogonal direction couples to the nodes of this node pencil. Node 0,0 is coupled 402 to communication pencil 400. Node 1,0 is coupled 404 to

5 communication pencil 400. Node 2,0 is coupled 406 to communication pencil 400. Node 3,0 is coupled 408 to communication pencil 400.

Consider the node pencil in the first orthogonal direction containing Node 0,1, Node 1,1, Node 2,1 and Node 3,1. The communication pencil 410 in the first orthogonal direction couples to the nodes of this node pencil. Node 0,1 is

10 coupled 412 to communication pencil 410. Node 1,1 is coupled 414 to communication pencil 410. Node 2,1 is coupled 416 to communication pencil 410. Node 3,1 is coupled 418 to communication pencil 410.

Consider the node pencil in the first orthogonal direction containing Node 0,2, Node 1,2, Node 2,2 and Node 3,2. The communication pencil 420 in the first

15 orthogonal direction couples to the nodes of this node pencil. Node 0,2 is coupled 422 to communication pencil 420. Node 1,2 is coupled 424 to communication pencil 420. Node 2,2 is coupled 426 to communication pencil 420. Node 3,2 is coupled 428 to communication pencil 420.

Consider the node pencil in the first orthogonal direction containing Node 0,3,

20 Node 1,3, Node 2,3 and Node 3,3. The communication pencil 430 in the first orthogonal direction couples to the nodes of this node pencil. Node 0,3 is coupled 432 to communication pencil 430. Node 1,3 is coupled 434 to communication pencil 430. Node 2,3 is coupled 436 to communication pencil 430. Node 3,3 is coupled 438 to communication pencil 430.

Figure **4C** depicts the two-dimensional plex communication grid of Figure **4A** with highlighted communication pencils **300, 310, 320** and **330** in the second orthogonal direction. Recall that a nodal pencil in the second orthogonal direction of a two-dimensional array contains the nodes **500** differing in only

5   the second dimensional component.

Consider the node pencil in the second orthogonal direction containing Node 0,0, Node 0,1, Node 0,2 and Node 0,3. The communication pencil **300** in the second orthogonal direction couples to the nodes of this node pencil. Node 0,0 is coupled **302** to communication pencil **300**. Node 0,1 is coupled **304** to

10   communication pencil **300**. Node 0,2 is coupled **306** to communication pencil **300**. Node 0,3 is coupled **308** to communication pencil **300**.

Consider the node pencil in the second orthogonal direction containing Node 1,1, Node 1,1, Node 1,2 and Node 1,3. The communication pencil **310** in the second orthogonal direction couples to the nodes of this node pencil. Node

15   1,0 is coupled **312** to communication pencil **310**. Node 1,1 is coupled **314** to communication pencil **310**. Node 1,2 is coupled **316** to communication pencil **310**. Node 1,3 is coupled **318** to communication pencil **310**.

Consider the node pencil in the second orthogonal direction containing Node 2,2, Node 2,1, Node 2,2 and Node 2,3. The communication pencil **320** in the

20   second orthogonal direction couples to the nodes of this node pencil. Node 2,0 is coupled **322** to communication pencil **320**. Node 2,1 is coupled **324** to communication pencil **320**. Node 2,2 is coupled **326** to communication pencil **320**. Node 2,3 is coupled **328** to communication pencil **320**.

Consider the node pencil in the second orthogonal direction containing Node 3,3, Node 3,1, Node 3,2 and Node 3,3. The communication pencil **330** in the second orthogonal direction couples to the nodes of this node pencil. Node 3,0 is coupled **332** to communication pencil **330**. Node 3,1 is coupled **334** to

5   communication pencil **330**. Node 3,2 is coupled **336** to communication pencil **330**. Node 3,3 is coupled **338** to communication pencil **330**.

Each of the communication pencils may be comprised of the number of communications paths required to interconnect each node of the corresponding node pencil directly to the other nodes of the corresponding

10   node pencil. Such embodiments of the invention advantageously support communications paths along each communication pencil based upon point-to-point physical transport layers, such as fiber optics, and microwave wave guides such as micro-channel.

These communications paths along each communication pencil

15   advantageously support point-to-point physical transport layers of various wireline structures, such as wire, fiber optics, twisted pair, coaxial cable, wave-guides such as micro-channel and free space lasers. Communication path support may include, but is not limited to, Wavelength Division Multiplexing (WDM). Communication pencils may advantageously support

20   Ethernet, ArcNet, Token Ring, FDDI and ATM as link layers. The communication gird may advantageously support network layers including, but not limited to, TCP/IP, Netware IPX, SMB and DecNet.

Figure **4D** depicts a two-dimensional plex communication grid with N=4 nodes **500**, each node **500** containing six ports in accordance with certain

25   embodiments of the invention. Note that M=2 and N=4. Each of the nodes

500 has M*(N-1), or six ports. Three of these ports on each node **500** are devoted to providing a direct interconnect to at least the other nodes **500** of its column through a collection of communication paths forming the communication pencil in the first orthogonal direction. The nodes **500**

5   belonging to the same column are the nodes **500** of the node pencil in the first orthogonal direction. The nodes **500** belonging to the same row are the nodes **500** of the node pencil in the second orthogonal direction.

Three of these ports on each node **500** are devoted to providing a direct interconnect to the other nodes **500** of its row through a collection of

10   communication paths forming the communication pencil in the second orthogonal direction. Those nodes **500** belonging to the same row are the nodes **500** of the node pencil in the second orthogonal direction.

In further embodiments of the invention, at least one node **500** has at least one additional port. At least one of the additional ports may be connected to

15   an external network. Further, at least one of the additional ports may be connected to an external mass storage system. In other embodiments of the invention, at least one of the additional ports may be connected to an external database system.

A node **500** may contain at least one instruction processor. As used herein,

20   an instruction processor includes but is not limited to instruction set processors, inference engines and analog processors. An instruction set processor refers to instruction processors changing state directly based upon an instruction, and which change an internal state by executing the instruction. Note that the instruction may include, but is not limited to, direct

25   or native instructions and interpreted instructions. An inference engine

changes state when presented an instruction, which may include a assertion, an assumption, or an inference rule. Inference engines include, but are not limited to, Horn clause engines such as Prolog requires, constraint based systems and neural network engines. As referred to herein, analog

5   processors include, but are not limited to, optical signal processors, CCD's, and resonant cavity devices responding to data and/or controls asserted in the analog domain.

Communication includes, but is not limited to, communication using a digital communications protocol. Communication also includes a messaging protocol

10   using the digital communications protocol. Communications also includes a messaging protocol compatibly supporting TCP-IP, supporting the Internet, and/or supporting the World Wide Web. Communications also includes link layers including but not limited to Ethernet, ArcNet, Token Ring, FDDI and ATM. Communication also includes network layers including, but not limited

15   to, TCP/IP, Netware IPX, SMB and DecNet.

Communications may also include at least one video stream protocol using a digital communications protocol. In further embodiments of the invention, communications includes at least one multi-media stream protocol using the video stream protocols which may include motion JPEG and may also include

20   at least one form of MPEG.

Further embodiments of the invention support Wavelength Division Multiplex (WDM) through the physical transport of the communication paths of the communication pencils.

Each node may include a communication processor. Each node may further include P communications processors. P may be a factor of number of communications ports required by the communications grid to couple with the node. The number of required ports may be $M^*(N-1)$, so that P becomes a

5 factor of $M^*(N-1)$. Such embodiments of the invention advantageously support communications processing at the node partitioned across the P communications processors.

N-1 may be a factor of P, where N is the maximum number of nodes in a node pencil of the array. N-1 may equal P. Alternatively, M may be a factor of P,

10 where M is the node array dimension. P may equal M, the node array dimension. Further, both N-1 and M may be a factor of P.

Figure 5 depicts a two-dimensional plex communication grid with N=4 nodes **500**, each node **500** containing six ports, two communications processors, each coupled to three ports in accordance with certain embodiments of the

15 invention. At least some of the nodes **500** may comprise multiple coupled communications processors, also known herein as Communications Processing Units (CPU).

Each CPU contains up to N-1 ports coupled to a communication pencil in one orthogonal direction. Differing CPU's may contain differing numbers of ports,

20 indicating differing numbers of nodes **500** in node pencils of differing orthogonal directions or additional communication to external networks, mass storage, database engines or servers, or other functional components.

M may be two. Such embodiments of the invention advantageously support two-dimensional plex communications networks. Such embodiments of the

invention provide communication between any two nodes in at most two hops, which is the same performance of communication as between nodes through a switch, but at considerably lower levels of complexity in terms of the interconnect scheme.

5   N may be four. Such embodiments of the invention advantageously support two dimensional plex communications networks with 16=4^2 nodes. Such embodiments of the invention have communication between any two nodes in at most two hops, compared to a toroidal 2-D mesh scheme, which requires up to four hops. A total direct-interconnect scheme would require 15 ports on

10   each node, compared with six for this embodiment of the invention. A 16 port communications switch is significantly more complex than the communication pencils of the plex communication grid taken collectively.

Figure **6** depicts the two communications pencils **410** and **320** coupled to Node 2,1 (**500**) and the two node pencils of Node 2,1 of Figure **4D** in

15   accordance with certain embodiments of the invention.

The node pencil in the first orthogonal direction includes Node 0,1, Node 1,1, Node 2,1 and Node 3,1. The couplings of these nodes to communication pencil **410** provides a direct interconnect between each node of the node pencil to the other nodes of the node pencil.

20   The node pencil in the second orthogonal direction includes Node 2,0, Node 2,1, Node 2,2 and Node 2,3. The couplings of these nodes to communication pencil **320** provides a direct interconnect between each node of the node pencil to the other nodes of the node pencil.

Figure **7** depicts the communications pencils and their coupling to the node pencils in the first orthogonal direction of the two-dimensional plex communications grid of Figure **4D** in accordance with certain embodiments of the invention. The node pencils are shown each comprised of the vertical node columns in Figure **7**.

The first displayed node pencil **400** in the first orthogonal direction includes Node(0,0), Node(1,0), Node(2,0) and Node(3,0). The couplings of these nodes **500** to communication pencil **400** provides a direct interconnect between each node **500** of the node pencil to at least the other nodes **500** of the node pencil.

The second displayed node pencil **410** in the first orthogonal direction includes Node(0,1), Node(1,1), Node(2,1) and Node(3,1). The couplings of these nodes to communication pencil **410** provides a direct interconnect between each node **500** of the node pencil at least to the other nodes **500** of the node pencil.

The third displayed node pencil **420** in the first orthogonal direction includes Node(0,2), Node(1,2), Node(2,2) and Node(3,2). The couplings of these nodes to communication pencil **420** provides a direct interconnect between each node **500** of the node pencil to the other nodes **500** of the node pencil.

The fourth displayed node pencil **430** in the first orthogonal direction includes Node(0,3), Node(1,3), Node(2,3) and Node(3,3). The couplings of these nodes **500** to communication pencil **430** provides a direct interconnect between each node **500** of the node pencil at least to the other nodes **500** of the node pencil.

Each of these node pencils couples to a corresponding communication pencil providing complete direct interconnect between at least pairs of nodes **500** of the node pencils. The communication pencils may include communication paths supporting the direct interconnect by use of N-1 ports at each node **500**

5   coupling to the communication pencil to provide the complete direct interconnect.

Figure **8** depicts the communications pencils and their coupling to the node pencils in the second orthogonal direction of the two-dimensional plex communications grid of Figure **4D** in accordance with certain embodiments of

10 the invention. The node pencils are each comprised of the horizontal node **500** rows in Figure **8**.

The first displayed node pencil **300** in the second orthogonal direction includes Node(0,0), Node(0,1), Node(0,2) and Node(0,3). The couplings of these nodes **500** to communication pencil **300** provides a direct interconnect

15 between each node **500** of the node pencil at least to the other nodes **500** of the node pencil.

The second displayed node pencil **310** in the second orthogonal direction includes Node(1,0), Node(1,1), Node(1,2) and Node(1,3). The couplings of these nodes **500** to communication pencil **310** provides a direct interconnect

20 between each node **500** of the node pencil to at least the other nodes **500** of the node pencil.

The third displayed node pencil **320** in the second orthogonal direction includes Node(2,0), Node(2,1), Node(2,2) and Node(2,3). The couplings of these nodes **500** to communication pencil **320** provides a direct interconnect

between each node **500** of the node pencil to at least the other nodes **500** of the node pencil.

The fourth displayed node pencil **330** in the second orthogonal direction includes Node(3,0), Node(3,1), Node(3,2) and Node(3,3). The couplings of

5 these nodes **500** to communication pencil **330** provides a direct interconnect between each node **500** of the node pencil at least to the other nodes **500** of the node pencil.

Each of these node pencils couples to a corresponding communication pencil providing complete direct interconnect between pairs of nodes **500** of the

10 node pencils. The communication pencils may include communication paths supporting the direct interconnect by use of N-1 ports at each node **500** coupling to the communication pencil to provide the complete direct interconnect.

Figure **9** depicts the communications pencils **410** and **320** coupled to Node

15 2,1 highlighting communication pencil **410** in the first orthogonal direction of Figures **4D** and **6**. The communication paths of the communication pencil **410** in the first orthogonal direction are shown in solid lines, and the communications paths of the communication pencil in the other orthogonal direction and nodes **500** of the node pencils are shown with broken lines.

20 Figure **10** depicts the communications pencils **410** and **320** coupled to Node 2,1 highlighting communication pencil **320** in the second orthogonal direction of Figures 4D and **6**. The communication paths of the communication pencil in the second orthogonal direction are shown in solid lines, and the

communications paths of the communication pencil in the other orthogonal direction and nodes **500** of the node pencils are shown with broken lines.

Figure **11** depicts the communications pencils **410** and **320** coupled to Node 2,1 highlighting the node pencil in the first orthogonal direction of Figures **4D**

5   and **6**. The nodes **500** of the node pencil in the first orthogonal direction are shown in solid lines, and the communications paths of the communication pencils and nodes **500** of the other node pencil are shown with broken lines.

Figure **12** depicts the communications pencils **410** and **320** coupled to Node 2,1 highlighting the node pencil in the second orthogonal direction of Figures

10 **4D** and **6**. The nodes **500** of the node pencil in the second orthogonal direction are shown in solid lines, and the communications paths of the communication pencils and nodes **500** of the other node pencil are shown with broken lines.

Figure **13A** depicts the difference between the embodiments of the invention

15 depicted in Figure **4D** of a 2-D, N=4 plex communications grid and the communications grid of a 2-D toroidal mesh interconnecting an N by N grid of nodes as shown in Figure **1C**. In Figure **13A**, communications paths common to the toroidal mesh and plex communications grid are shown with solid lines. Communications paths found only in the plex communications grid are shown

20 in broken lines.

Figure **13B** depicts a 2-D, N=4 toroidal grid of the prior art mapped onto a torus, in a fashion similar to Figure **2B**. Figure **13C** depicts the difference between the embodiments of the invention depicted in Figure **4D** of a 2-D, N=4 plex communications grid and the communications grid of a 2-D toroidal

37

mesh interconnecting an N by N grid of nodes as shown in Figure **13B**. Figure **13C** is equivalent to the connectivity of Figure **13A** and has been provided to show in a more graphic form distinctions pointed out in Figure **13A**.

5   Several things become apparent from study of Figure **13A**, the mesh array of Figure **1C** and Figures **13B** and **13C**. First, each node in a 2-D mesh, whether or not it is toroidal, requires no more than four ports to interconnect with the communications network. Plex communications nodes require more. For the 2-D case, with N=4, each node of coupled to the plex communication grid as shown in Figure **4D** requires six ports. It is not possible for the mesh

10   node with no more than 4 ports of Figure **1C** to substitute functionally for the nodes of the plex communications scheme as shown in Figure **4D**.

Secondly, it takes two hops for communication between Node (2,0) and Node(2,2) in the mesh communications schemes, whether toroidal or not. In the plex communications grid, it takes one hop to communicate between

15   Node(2,0) and Node(2,2), or any other pair of nodes of that row.

Thirdly, it takes two hops for communication from Node(2,2) to Node(0,2) in the mesh communications schemes, whether toroidal or not. In the plex communications grid, it takes one hop to communicate between these nodes, or any other pair of nodes of that column.

20   Thus, it can take four hops for a communication to go from Node(2,0) to Node(0,2) in the above described mesh communications schemes, whereas it takes only two hops in the plex communications grid. Note when N=6, a two-dimensional toroidal mesh communications scheme can take up to six hops to communicate between Node(3,0) and Node(0,3), whereas the plex

communications grid would still require at most two hops to communicate between any two nodes.

M may be three. Such embodiments of the invention advantageously support three-dimensional plex communications networks.

5   Figure 14 depicts a three-dimensional array of N=5 nodes 500 with orthogonal directions 490, 492 and 494 in accordance with the invention. In Figure 14, each intersection of lines depicts a node 500. This has been shown schematically to simplify Figure 14, and is not meant to limit the contents of a node in any way.

10   Figure 15 depicts some of the node pencils and corresponding communications pencils in the first orthogonal direction of a three-dimensional array of 4*5*5 nodes 500 in accordance with certain embodiments of the invention. The first node pencil shown in the first orthogonal direction contains Node(0,0,2), Node(1,0,2), Node(2,0,2), and Node(3,0,2). The first

15   communication pencil 700 is coupled to the first node pencil providing direct interconnection between each pair of nodes 500 of the first communication pencil.

The second node pencil in the first orthogonal direction contains Node(0,1,2), Node(1,1,2), Node(2,1,2), and Node(3,1,2). The second communication

20   pencil 702 is coupled to the second node pencil providing direct interconnection between each pair of nodes 500 of the second communication pencil.

The third node pencil in the first orthogonal direction contains Node(0,2,2), Node(1,2,2), Node(2,2,2), and Node(3,2,2). The third communication pencil

704 is coupled to the third node pencil providing direct interconnection between each pair of nodes **500** of the third communication pencil.

The fourth node pencil in the first orthogonal direction contains Node(0,3,2), Node(1,3,2), Node(2,3,2), and Node(3,3,2). The fourth communication pencil

5 **706** is coupled to the fourth node pencil providing direct interconnection between each pair of nodes **500** of the fourth communication pencil.

The fifth node pencil in the first orthogonal direction contains Node(0,4,2), Node(1,4,2), Node(2,4,2), and Node(3,4,2). The fifth communication pencil **708** is coupled to the fifth node pencil providing direct interconnection

10 between each pair of nodes **500** of the fifth communication pencil.

Each node pencil in the first orthogonal direction contains four nodes. In this embodiment of the invention, each node may contain three ports coupled to the corresponding communication pencil to provide complete direct interconnect.

15 Figure **16** depicts some of the node pencils and corresponding communications pencils in the second orthogonal direction of a three-dimensional array of 4*5*5 nodes **500** in accordance with certain embodiments of the invention.

The first shown node pencil contains Node(0,0,2), Node(0,1,2), Node(0,2,2),

20 Node(0,3,2), and Node(0,4,2). The first communication pencil **730** is coupled to the first node pencil providing direct interconnection between each pair of nodes **500** of the first communication pencil.

The second node pencil contains Node(1,0,2), Node(1,1,2), Node(1,2,2), Node(1,3,2), and Node(1,4,2). The second communication pencil **732** is coupled to the second node pencil providing direct interconnection between each pair of nodes **500** of the second communication pencil.

5   The third node pencil contains Node(2,0,2), Node(2,1,2), Node(2,2,2), Node(2,3,2), Node(2,3,2), and Node(2,4,2). The third communication pencil **734** is coupled to the third node pencil providing direct interconnection between each pair of nodes **500** of the third communication pencil.

The fourth node pencil contains Node(3,0,2), Node(3,1,2), Node(3,2,2),
10   Node(3,3,2), Node(3,3,2), and Node(3,4,2). The fourth communication pencil **736** is coupled to the fourth node pencil providing direct interconnection between each pair of nodes **500** of the fourth communication pencil.

Each node pencil in the second orthogonal direction contains five nodes. In this embodiment of the invention, each node may contain four ports coupled
15   to the corresponding communication pencil to provide complete direct interconnect.

Figure **17** depicts some of the node pencils and corresponding communications pencils in the third orthogonal direction of a three-dimensional array of 4*5*5 nodes **500** in accordance with certain
20   embodiments of the invention. The first shown node pencil contains Node(0,0,0), Node(0,0,1), Node(0,0,2), Node(0,0,3), and Node(0,0,4). The first communication pencil **750** is coupled to the first node pencil providing direct interconnection between each pair of nodes **500** of the first communication pencil.

41

The second node pencil contains Node(0,1,0), Node(0,1,1), Node(0,1,2), Node(0,1,3), and Node(0,1,4). The second communication pencil **752** is coupled to the second node pencil providing direct interconnection between each pair of nodes **500** of the second communication pencil.

5   The third node pencil contains Node(0,2,0), Node(0,2,1), Node(0,2,2), Node(0,2,3), and Node(0,2,4). The third communication pencil **754** is coupled to the third node pencil providing direct interconnection between each pair of nodes **500** of the third communication pencil.

The fourth node pencil contains Node(0,3,0), Node(0,3,1), Node(0,3,2), 10   Node(0,3,3), and Node(0,3,4). The fourth communication pencil **756** is coupled to the fourth node pencil providing direct interconnection between each pair of nodes **500** of the fourth communication pencil.

The fifth node pencil contains Node(0,4,0), Node(0,4,1), Node(0,4,2), Node(0,4,3), and Node(0,4,4). The fifth communication pencil **758** is coupled 15   to the fifth node pencil providing direct interconnection between each pair of nodes **500** of the fifth communication pencil.

Each node pencil in the third orthogonal direction contains five nodes. In this embodiment of the invention, each node may contain four ports coupled to the corresponding communication pencil to provide complete direct interconnect.

20   Note that M may be four. Such embodiments of the invention advantageously support four-dimensional plex communications networks.

Figure **18A** depicts a node **500** with up to M*(N-1) ports **506** which couple to the communication pencils of the node **500** which intersect at the node **500** in

an M-dimensional array in accordance with certain embodiments of the invention. A node **500** may contain M*(N-1) ports **506** which couple to the communication pencils of the node which intersect at the node in an M-dimensional array.

5   The physical transport layers of the communications paths coupled to ports **506** may be essentially the same. The communications protocols of the communications paths coupled to ports **506** may be essentially the same. In other further embodiments of the invention, the communications protocols of the communications paths coupled to ports **506** are not essentially the same.

10   The physical transport layer of the communication paths coupled to ports **506** may not be all essentially the same. In further embodiments of the invention, the communications protocols of the communications paths coupled to ports **506** are essentially the same. In other further embodiments of the invention, the communications protocols of the communications paths coupled to ports
15   **506** are not essentially the same.

One or more additional ports **508** may be contained in at least one node **500**. The physical transport layers of communications paths coupled to two or more of these additional ports **508** may be essentially the same. The communications protocols of the communications paths coupled to ports **508**
20   may be essentially the same. In other further embodiments of the invention, the communications protocols of the communications paths coupled to ports **508** are not essentially the same.

The physical transport layer of communications paths coupled to two or more of these additional ports **508** may not be essentially the same. In further

43

embodiments of the invention, the communications protocols of the communications paths coupled to ports **508** are essentially the same. In other further embodiments of the invention, the communications protocols of the communications paths coupled to ports **508** are not essentially the same.

5   At least one node **500** may be accessibly coupled **502** to memory **504**. In further embodiments of the invention, node **500** contains an instruction processor further accessibly coupled **502** to memory **504**. In further embodiments of the invention, node **500** contains at least two instruction processors. In further embodiments of the invention, node **500** contains

10   multiple instruction processors accessibly coupled **502** to memory **504**.

Recall that each node may include a communication processor. Each node may further include P communications processors. P may be a factor of the number of communications ports required by the communications grid to couple with the node. The number of required ports may be $M^*(N-1)$, so that P

15   becomes a factor of $M^*(N-1)$. Such embodiments of the invention advantageously support communications processing at the node partitioned across the P communications processors.

Further recall that N-1 may be a factor of P, where N is the maximum number of nodes in a node pencil of the array. N-1 may equal P. Alternatively, M may

20   be a factor of P, where M is the node array dimension. P may equal M, the node array dimension. Further, both N-1 and M may be a factor of P.

The P communications processors may be coupled by a bus. Such embodiments of the invention advantageously support the use of a bus to couple the P communications processors of a node. Further additional

embodiments of the invention include the bus coupling the P communications processors supporting a bus master. Further embodiments of the invention include the bus master as one of the P communications processors. Further embodiments of the invention include the bus master, over time, being any of

5   the P communications processors.

As used herein, a bus refers to a common communication coupling between multiple communicating devices. As used herein, bus master refers to a device controlling which of the communicating devices coupled to the controlled bus may actively communicate or access the bus. It is common for

10   some of the coupled communicating devices to have to wait for bus access.

Figure **18B** depicts a node **500** with up to P CPU's **510, 520, 550** and **560** coupled by **530-536** to the communication pencils of node **500** which intersect at node **500** in an M-dimensional array in accordance with certain embodiments of the invention. To minimize the complexity of the drawing and

15   discussion, Figure **18B** shows embodiments of the invention for P equal to four. This is done strictly to minimize the complexity of the discussion and not to impose a limitation upon interpretation of the claims. In certain embodiments of the invention, P is two. In other further embodiments of the invention, P is three. In other further embodiments of the invention, P is four.

20   In certain other embodiments of the invention, P is at least five.

At least one node **500** contains P CPU's **510, 520, 550** and **560** coupled by **530-536**. Couplings **530-536** may form a single shared coupling **530**. A bus may provide coupling **530**. A bus may be considered as a resource allowing a limited subset of processors to simultaneously communicate. Buses are often

found to require at least some combinations of processors to sometimes wait before communicating, which is often referred to as bus access.

A bus arbitration scheme may control access to coupling 530. A bus master may further control the bus providing coupling 530. In further embodiments of
5   the invention, one of the CPUs acts as the bus master controlling coupling 530. In further embodiments of the invention, any of the CPUs may act as the bus master controlling coupling 530. In further embodiments of the invention, all of the CPUs occasionally act as the bus master controlling coupling 530.

Couplings 530-536 may form a single shared coupling 530 of the CPUs 510
10 and 520 with a specific interface 532 via 534 to CPU 550 and via 536 to CPU 550. Couplings 534 and 536 may further act as a bus with interface 532 acting as a bridge between coupling 530 and bus 534-536.

Couplings 530-536 may form a single shared coupling 530 of the CPUs 510 and 520 with coupling 530-532-534 acting as a direct interface of CPU 550 to
15 one of CPUs 510 and 520. Coupling 530-532-536 may further act as a direct interface of CPU 560 to one of CPUs 510 and 520. Coupling 530-532-536 may also further act as a direct interface of CPU 560 to the shared coupling 530 of CPUs 510 and 520.

Node 500 may contain CPU 510 further accessibly coupled 512 to memory
20 514. Node 500 may contain CPU 520 accessibly coupled 522 to memory 524. Node 500 may contain CPU 550 accessibly coupled 552 to memory 554. Node 500 may contain CPU 560 accessibly coupled 562 to memory 564.

Two or more of the memories 514, 524, 554 and 564 may be contained within a single package. As used herein, a package includes but is not limited to a

printed circuit board, an assembly including a printed circuit board, a multi-chip module, an integrated circuit, a circuit encased in one or more of the collection, including but not limited to, plastic, ceramic, metallic and optically conductive materials. The package may further include power distribution components. The package may also further include thermal dissipation components.

One or more of the CPUs **510, 520, 550,** and **560** may be contained within a single package with the respective accessibly coupled memories **514, 524, 554** and **564**.

At least one of the CPUs **510** may contain up to M*(N-1) ports **516**. Each of the CPUs **510, 520, 550,** and **560** may contain up to M*(N-1)/P ports **516**. Each of the CPUs **510, 520, 550,** and **560** may further contain at least N-1 ports **516, 526, 556** and **566**, coupling to the communication paths of communication pencils in the M orthogonal directions. In further embodiments of the invention, each of the CPUs **510, 520, 550,** and **560** contain N-1 ports **516, 526, 556,** and **566** coupling to the communication paths of communication pencils in the M orthogonal directions. Each of the CPUs **510, 520, 550,** and **560** may contain M ports **516, 526, 556** and **566**, coupling to the communication paths of communication pencils in the M orthogonal directions.

At least one of the CPUs **510** may contain at least one additional port **518**. In further embodiments of the invention, each of the CPUs **510, 520, 550** and **560** may contain at least one additional port **518, 528, 558** and **568**. In certain embodiments of the invention one or more of these additional ports couple to external communications networks. In certain embodiments of the invention

one or more of these additional ports couple to an external database engine. In certain embodiments of the invention one or more of these additional ports couple to a server.

At least one of the communications processors may be further comprised of at 5 least one instruction processor accessibly coupled to a memory. Such embodiments of the invention advantageously support instruction processing at each of the communications processors.

At least one of the communications processors **510** may include a communication handler coupled to at least one of the ports **516**. The 10 communication handler may include, but is not limited to, a finite state machine. The finite state machine may include, but is not limited to, one or more programmable logic circuits, Field Programmable Logic Arrays (FPGAs), gate arrays, standard cell circuits. Such embodiments of the invention advantageously support protocol handlers for digital protocols, which are often 15 advantageously implemented, at least in part, as finite state machines. Note that the finite state machine may change state synchronously or asynchronously. Synchronous finite state machines may use a synchronizing mechanism based upon the condition of coupled port(s) **516**, or based upon one or more conditions within the node **500**.

20 The communication handler may further include, but is not limited to, transmitter, receiver or transceiver circuitry interfacing to at least one of the physical transport layers of the port, for at least one of the ports. Such embodiments of the invention advantageously support physical transport layer interfaces.

At least one, possibly all, of the communications processors may be comprised of a communications instruction processor accessibly coupled to the memory. The communications instruction processor is communicatively coupled to at least one of the ports. The communications processor may be

5   communicatively coupled to the port via the communication handler. Such embodiments of the invention advantageously support communications instruction processors coupled to at least some of the ports. Programmable communications processing further advantageously supports encryption, security, and other activities requiring reconfiguration over time.

10   The M communications processors may be coupled by a direct connection network of each of the M communications processors coupled directly to each of the remaining communications processors. Such embodiments of the invention advantageously support the communications processors coupled by a direct connection network, where each communications processor is directly

15   coupled to every other communications processor of the node. This advantageously avoids having to wait for bus access.

Figure 19 depicts a node 500 with up to P CPU's 510, 520, 550 and 560 directly coupled by 538-548, with ports 516, 526, 556 and 566 which couple to the communication pencils of the node pencils intersecting at the node 500 in

20   an M-dimensional array in accordance with certain embodiments of the invention. To minimize the complexity of the drawing and discussion, Figure 19 shows embodiments of the invention for P equal to four. This is done strictly to minimize the complexity of the discussion and not to impose a limitation upon interpretation of the claims. In further embodiments of the

25   invention, P is two. In other further embodiments of the invention, P is three.

In other further embodiments of the invention, P is four. In certain other embodiments of the invention, P is at least five.

As in Figure 18B, at least one node 500 contains P coupled CPU's 510, 520, 550 and 560. Node 500 contains CPU 510 further accessibly coupled 512 to memory 514. In further embodiments of the invention, node 500 contains CPU 520 accessibly coupled 522 to memory 524. In further embodiments of the invention, node 500 contains CPU 550 accessibly coupled 552 to memory 554. In further embodiments of the invention, node 500 contains CPU 560 accessibly coupled 562 to memory 564.

As in Figure 18B, two or more of the memories 514, 524, 554 and 564 may be contained within a single package.

As in Figure 18B, one or more of the CPUs 510, 520, 550, and 560 may be contained within a single package with the respective accessibly coupled memories 514, 524, 554 and 564.

As in Figure 18B, at least one of the CPUs 510 may contain up to $M*(N-1)$ ports 516. Each of the CPUs 510, 520, 550, and 560 may contain up to $M*(N-1)/P$ ports 516. Each of the CPUs 510, 520, 550, and 560 may further contain at least N-1 ports 516, 526, 556 and 566, coupling to the communication paths of communication pencils in the M orthogonal directions. In further embodiments of the invention, each of the CPUs 510, 520, 550, and 560 contain N-1 ports 516, 526, 556, and 566 coupling to the communication paths of communication pencils in the M orthogonal directions. Each of the CPUs 510, 520, 550, and 560 may contain M ports 516, 526, 556 and 566,

coupling to the communication paths of communication pencils in the M orthogonal directions.

As in Figure **18B**, at least one of the CPUs **510** may contain at least one additional port **518**. In further embodiments of the invention, each of the CPUs **510**, **520**, **550** and **560** contain at least one additional port **518**, **528**, **558** and **568**. In certain embodiments of the invention one or more of these additional ports couple to external communications networks. In certain embodiments of the invention one or more of these additional ports couple to an external database engine. In certain embodiments of the invention one or more of these additional ports couple to a server.

When P=2, CPU **510** couples via **538** to CPU **520**, which is similar to the situation described in Figure **18B**. When P=3, additional couplings **540** and **542** connect CPU **510** with CPU **550** and CPU **520** with CPU **550**, respectively. This supports each CPU being able to independently directly communicate with any of the other CPUs without having to wait for bus access.

When P=4, additional couplings **548**, **546** and **544** connect CPU **510** with CPU **560**, CPU **520** with CPU **560** and CPU **550** with CPU **560**, respectively. This supports each CPU being able to independently directly communicate with any of the other CPUs without having to wait for bus access.

Note that the physical transport layers of the couplings **538-548** may differ from the physical transport layers of one or more of the communication pencils coupled to the various ports **516**, **518**, **526**, **528**, **566**, **568**, **556**, and **558**. The physical transport layers of the couplings **538-548** of one node **500**

may differ from another node's physical transport layers for couplings **538-548**.

Certain nodes may be implemented as in Figure **18B**, while other nodes may be implemented as in Figure **19**. Certain plex communications grids may use
5   at least one node, which is itself a plex communication grid.

Node level handling of communications processing and routing is a well developed topic in the prior art which one of ordinary skill readily understands to include, but not be limited to, message passing, stream processing, encryption, error control coding, gateways, fire walls, TCP-IP, Internet, and
10   web-sites.

Communication across a communication pencil includes traversal of the physical transport(s) of the relevant communication path of the communication pencil. Thus, traversing the communication grid along a collection of communication pencils includes traversal of the physical
15   transports of communication paths of those communication pencils.

As is obvious to one of ordinary skill, the physical transport layers of the communication paths within a node as well as communication paths within a communication pencil include, but are not limited to, one or more wires, twisted pairs of wires, and wave guides. Wave guides as used herein include,
20   but are not limited to, coaxial cable, fiber optics and micro-channels. These physical transports may further support communications protocols in the radio, microwave, infra-red and optical, ultra-violet frequency domains. Such protocols include but are not limited to frequency modulation, time division

multiple access, wavelet division multiple access, wavelength division multiple access (WDM) and soliton transmission technologies.

As is obvious to one of ordinary skill, traversing a physical transport layer may include entering the physical transport layer, crossing the physical transport layer and leaving the physical transport layer. Entering and leaving a physical transport layer may be performed by, at least, various electronic, electro-optical, opto-electronic and resonant cavity devices including but not limited to diode and transistor structures, lasers and various tuned crystalline structures.

As is obvious to one of ordinary skill, traversing a first and a second physical transport layer may include the following. Traversing the first physical transport layer. Traversing between the first physical transport layer and the second physical transport layer. And traversing the second physical transport layer. Traversing between first and second physical transport layers may be performed by, at least, various electronic, electro-optical, opto-electronic and resonant cavity devices including but not limited to diode and transistor structures, lasers and various tuned crystalline structures.

Certain embodiments of the invention include a method of communicating from a first node to a second node in a multi-dimensional lattice of nodes through a communications network, in accordance with certain embodiments of the invention. The second node differs from the first node in R dimensional components, where R is a number between 0 (if the nodes are the same) and M (if the nodes differ in every orthogonal direction's component). The communication traverses a node pencil path comprised of R-1 successive intermediate nodes. Each of the successive intermediate nodes has one less dimensional component differing from the second node. Each node pencil

53

has a coupled corresponding communication pencil containing at least one physical transport.

Figure **20A** depicts a system **600** containing an M=2, N=4 plex communication grid with 16=N^M nodes **500**, with one node **500** including four communication processing units (CPUs), three nodes **500** including three CPUs, and 12 nodes **500** including two CPUs, where the 3 CPU nodes each are further coupled to external communications networks and each possess a tunneling interface, in accordance with certain embodiments of the invention.

Nodes **500** (0,0), (1,1), and (2,2) each include three communication processing units (CPUs) **510**, **520**, and **550**. Node **500** (3,3) includes four CPUs **510**, **520**, **550**, and **560**. All Nodes **500** include CPUs **510** and **520**. Each CPU **510** is accessibly coupled **512** to memory **514**. Each CPU **520** is accessibly coupled **522** to memory **524**. Each CPU **550** is accessibly coupled **552** to memory **554**. Note that the reference numbers **512**, **522** and **552** are not shown to minimize the complexity of the figure. CPU **560** may further include an accessibly coupled memory.

Each of the CPUs **550** includes a tunneling interface coupling to a communications tunnel. CPU **550** of Node **500** (0,0) couples to communications tunnel **640**. CPU **550** of Node **500** (1,1) couples to communications tunnel **642**. CPU **550** of Node **500** (2,2) couples to communications tunnel **644**. CPU **550** of Node **500** (3,3) couples to communications tunnel **646**.

Any node **500** may include additional communications interfaces to add further communications capabilities.

By way of example, Figure **20A** shows Node **500** (1,1) CPU **550** may include communications interfaces **610** and **612**. Node **500** (2,2) CPU **550** may include communications interfaces **606** and **608**. Node **500** (3,3) CPU **550** may include communications interfaces **602** and **604**. One or more of these 5 CPU **550** may include circuitry to select one of the two communications interfaces to be actively utilized. One or more of these CPU **550** may concurrently use both communications interfaces.

Figure **20A** shows Node **500** (3,3) CPU **520** with an accessibly coupled memory **524** which includes a ROM.

10 Any node **500** may have one or more CPUs accessibly coupled to one or more memories. That accessibly coupled memory may include an accessibly coupled non-volatile memory component. That accessibly coupled non-volatile memory component may include ROM, flash memory, EPROM, EEPROM, CD-ROM, DVD-ROM components accessibly coupled to one or 15 more of the CPUs of a node. The non-volatile memory component may further support a file management system interface through the accessibly coupled CPU.

Figure **20A** shows Node **500** (3,3) CPU **560** has a communication interface **670** which may further couple to a mass storage system, database engine, 20 network gateway, or specialized engine.

Any node **500** may include such additional communication capabilities. The system **600** may further support distributed access to such resources by use of an access protocol which is compatible with the communications protocols in use on at least some of the communication pencils. By way of example, file

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access to a mass storage system may be through a TCP-IP compatible protocol, such as LDAP. Access to a database engine may be through a TCP-IP compatible protocol such as XML or through a CORBA compatible object structure protocol.

5   Figure **20B** alternatively depicts a system **600** containing an M=2, N=4 plex communication grid with 16=N^M nodes **500**, with one node **500** including four communication processing units (CPUs), three nodes **500** including three CPUs, and 12 nodes **500** including two CPUs, where the 3 CPU nodes each are further coupled to external communications networks and each possess a

10   tunneling interface, in accordance with certain embodiments of the invention.

As in Figure **20A**, Nodes **500** (1,1), and (2,2) each include three communication processing units (CPUs) **510, 520**, and **550**.

Node **500** (0,0) includes four CPUs **510, 520, 550**, and **560**. Nodes **500** (3,3) includes three communication processing units (CPUs) **510, 520**, and **550**.

15   As in Figure **20A**, all Nodes **500** include CPUs **510** and **520**. Each CPU **510** is accessibly coupled **512** to memory **514**. Each CPU **520** is accessibly coupled **522** to memory **524**. Each CPU **550** is accessibly coupled **552** to memory **554**. Note that the reference numbers **512, 522** and **552** are not shown to minimize the complexity of the figure. CPU **560** may further include

20   an accessibly coupled memory.

As in Figure **20A**, each of the CPUs **550** includes a tunneling interface coupling to a communications tunnel.

However, Figure **20B** shows CPU **550** of Node **500** (3,3) couples to communications tunnel **640**. CPU **550** of Node **500** (2,2) couples to communications tunnel **642**. CPU **550** of Node **500** (1,1) couples to communications tunnel **644**. CPU **550** of Node **500** (0,0) couples to

5   communications tunnel **646**.

As in Figure **20A**, any node **500** may include additional communications interfaces to add further communications capabilities.

Figure **20B** shows Node **500** (3,3) CPU **550** may include communications interfaces **610** and **612**. Node **500** (2,2) CPU **550** may include

10   communications interfaces **606** and **608**. Node **500** (1,1) CPU **550** may include communications interfaces **602** and **604**. One or more of these CPU **550** may include circuitry to select one of the two communications interfaces to be actively utilized. One or more of these CPU **550** may concurrently use both communications interfaces.

15   Figure **20B** shows Node **500** (0,0) CPU **520** with an accessibly coupled memory **524** which includes a ROM.

Any node **500** may have one or more CPUs accessibly coupled to one or more memories. That accessibly coupled memory may include an accessibly coupled non-volatile memory component. That accessibly coupled non-

20   volatile memory component may include ROM, flash memory, EPROM, EEPROM, CD-ROM, DVD-ROM components accessibly coupled to one or more of the CPUs of a node. The non-volatile memory component may further support a file management system interface through the accessibly coupled CPU.

Figure 20B shows Node 500 (0,0) CPU 560 has a communication interface 670 which may further couple to mass storage system, database engine, network gateway, or specialized engine.

Any node 500 may include such additional communication capabilities. The
5   system 600 may further support distributed access to such resources by use of an access protocol which is compatible with the communications protocols in use on at least some of the communication pencils. By way of example, file access to a mass storage system may be through a TCP-IP compatible protocol, such as LDAP. Access to a database engine may be through a
10 TCP-IP compatible protocol such as XML or through a CORBA compatible object structure protocol.

Figure 21 depicts a system 800 including two instances of system 600 as depicted in Figures 20A and 20B, referred to as 600-1 and 600-2, in accordance with certain embodiments of the invention.

15 Figure 21 depicts system 800 including 6 external communications mechanisms 802-812 each coupling respectively to 602-612 of system 600-1 and coupling respectively to 602-612 of system 600-2. Note that these external communication mechanisms may use the same physical transport layer mechanism, or that they may differ. Whether or not these external
20 communications mechanisms use the same physical transport layer mechanism, they may use similar communications protocols, or they may use dissimilar communications protocols.

Figure 21 depicts system 800 including resource pool 830 coupled 832 to system 600-1 by communication interface 670. The resource pool 830 is

coupled **834** to system **600-2** by communication interface **670**. The resource pool **830** may include but is not limited to one or more of the following: mass storage systems, database engines, network gateways and specialized engines. Couplings **832** and **834** may each include more than one

5   communication mechanism. Each of the communications mechanisms included in couplings **832** and **834** may involve more than one physical transport layer. The communication mechanisms included in couplings **832** and **834** may or may not employ similar physical transport layers. The communication mechanisms included in couplings **832** and **834** may or may

10 not employ compatible communications protocols.

The systems **600-1** and **600-2** may further support distributed access to Resource Pool **830** by use of an access protocol compatible with communications protocols in use on at least some of the communication pencils of their respective internal communications grids. By way of example,

15 file access to a mass storage system may be through a TCP-IP compatible protocol, such as LDAP. Access to a database engine may be through a TCP-IP compatible protocol such as XML or through a CORBA compatible object structure protocol.

System **600-1** may be provided **842** power supply **840**. System **600-2** may be

20 provided **846** power supply **844**. Such independent power supplies can cost-effectively add to the overall reliability of the system **800**, because if one power supply fails, at least half of the system **600** components continue to function. The total cost of two of these power supplies is considerably less than the cost a single power supply, plus supply backup to power both system

25 **600's**.

Certain embodiments of the invention are applicable to other multi-dimensional arrays of computers.

Figure **22** partially depicts a toroidal three-dimensional mesh communication grid for an N=3, three dimensional (M=3) array of nodes **500**, each comprising P=2 Communication Processor Units (CPU) which each comprise M=3 ports for the corresponding communication pencils.

Consider communication between a first node **500** and a second node **500**, when the first node and second node are both coupled to communication pencils coupling to a third node **500**. The first node **500** couples to a first communication pencil coupled to a third node **500**. The third node **500** couples to a second communication pencil coupled to the second node **500**. Each of the communication pencils includes at least one physical transport layer.

Figure **23A** depicts a flowchart of a method communicating between a first node **500** and a second node **500** when the first node **500** and second node **500** are both coupled to communication pencils coupling to a third node **500**, in accordance with certain embodiments of the invention.

Operation **1000** starts the operations of this flowchart. Arrow **1002** directs the flow of execution between operation **1000** and operation **1004**. Operation **1004** performs the first node communicating with the third node via the first communication pencil. Arrow **1006** directs execution between operation **1004** and operation **1008**. Operation **1008** performs the third node communicating with the second node via the second communication pencil. Arrow **1010**

directs execution between operation **1008** and operation **1012**. Operation **1012** terminates the operations of this flowchart.

Note that Figure **23A** permits the operations of this flowchart to begin at the exit operation **1012** and exit at the beginning operation **1000**. This, while

5   unusual, has been done to point out the ability of any element of the communication being an initiator or terminator of the operations depicted in this Figure.

Figure **23B** depicts a detail flowchart of operation **1004** of Figure **23A** further performing the first node communicating with the third node via the first

10   communication pencil.

Arrow **1030** directs the flow of execution from starting operation **1004** to operation **1032**. Operation **1032** performs traversing all of the physical transport layers included in the first communication pencil. Arrow **1034** directs execution from operation **1032** to operation **1036**. Operation **1036** terminates

15   the operations of this flowchart.

Figure **23C** depicts a detail flowchart of operation **1012** of Figure **23A** further performing the third node communicating with the second node via the second communication pencil.

Arrow **1050** directs the flow of execution from starting operation **1012** to

20   operation **1052**. Operation **1052** performs traversing all of the physical transport layers included in the second communication pencil. Arrow **1054** directs execution from operation **1052** to operation **1056**. Operation **1056** terminates the operations of this flowchart.

In certain embodiments of the invention, a communication pencil may include exactly one physical transport layer. However, a communication pencil may include a first physical transport layer and a second physical transport layer. Two communication pencils of a single embodiment of the invention may

5 include different physical transport layers and differing numbers of physical transport layers. A communication pencil may include a bus. The communication pencil may implement a Time Division Multiple Access (TDMA) protocol.

Figure 24A depicts a detail flowchart of operation 1032 of Figure 23B further

10 performing traversing the physical transport layers when the first communication pencil includes a first physical transport layer and second physical transport layer.

Arrow 1070 directs the flow of execution from starting operation 1032 to operation 1072. Operation 1072 performs traversing the first physical

15 transport layer. Arrow 1074 directs execution from operation 1072 to operation 1076. Operation 1076 terminates the operations of this flowchart.

Arrow 1080 directs the flow of execution from starting operation 1032 to operation 1082. Operation 1082 performs traversing between the first physical transport layer and the second physical transport layer. Arrow 1084

20 directs execution from operation 1082 to operation 1076. Operation 1076 terminates the operations of this flowchart.

Arrow 1090 directs the flow of execution from starting operation 1032 to operation 1092. Operation 1092 performs traversing the second physical

transport layer. Arrow **1094** directs execution from operation **1092** to operation **1076**. Operation **1076** terminates the operations of this flowchart.

Figure **24B** depicts a detail flowchart of operation **1052** of Figure **24C** further performing traversing the physical transport layers when the communication

5 pencil includes a first physical transport layer and second physical transport layer.

Arrow **1110** directs the flow of execution from starting operation **1052** to operation **1112**. Operation **1112** performs traversing the first physical transport layer. Arrow **1114** directs execution from operation **1112** to

10 operation **1116**. Operation **1116** terminates the operations of this flowchart.

Arrow **1120** directs the flow of execution from starting operation **1052** to operation **1122**. Operation **1122** performs traversing between the first physical transport layer and the second physical transport layer. Arrow **1124** directs execution from operation **1122** to operation **1116**. Operation **1116**

15 terminates the operations of this flowchart.

Arrow **1130** directs the flow of execution from starting operation **1052** to operation **1132**. Operation **1132** performs traversing the second physical transport layer. Arrow **1134** directs execution from operation **1132** to operation **1116**. Operation **1116** terminates the operations of this flowchart.

20 By way of example of the operation of Figures **23A-23C, 24A** and **24B**, consider communication for a 2-D array based upon Figure **4A**. M is 2. Given any two nodes, they either have the same address in the array, differ by one dimensional component or differ by both dimensional components.

When two nodes have the same address, they are the same node. Communications within a node, while important, will be postponed briefly.

Consider two nodes differing by one dimensional component, say Node **500** (0,0) and Node **500** (1,0), which differ in the first dimensional component.

5   Node **500** (0,0) couples **402** to communication pencil **400** and Node **500** (1,0) couples **404** to communication pencil **400**. Communication between Node **500** (0,0) and Node **500** (1,0) entails Node **500** (0,0) communicating with Node **500** (1,0) via communication pencil **400**. Node **500** (0,0) communicating with Node **500** (1,0) via communication pencil **400** further includes traversing all of

10   the physical transport layers in communication pencil **400**.

Consider communication between first Node **500** (0,0) and second Node **500** (1,1), which differ by two dimensional components. These nodes are not coupled to a common communication pencil. However, there are a number of choices of a third node sharing a common dimensional component with each

15   of them. Such choices for the third node include Node **500** (1,0) and Node **500** (0,1). For the sake of discussion, select Node **500** (1,0). Node **500** (0,0) couples **402** to a first communication pencil **400** and Node **500** (1,0) couples **404** to first communication pencil **400**. Node **500** (1,0) couples **312** to a second communication pencil **310** and Node **500** (1,1) couples **314** to second

20   communication pencil **310**.

Communication between first Node **500** (0,0) and second Node **500** (1,1) may be achieved by first Node **500** (0,0) communicating with third Node **500** (1,0) via first communication pencil **400** (step of **1004** of Figure **23A**) and third Node **500** (1,0) communicating with second Node **500** (1,1) via second

25   communication pencil **310** (step of **1008** of Figure **23A**).

64

First Node **500** (0,0) communicating with third Node **500** (1,0) via first communication pencil **400** (step of **1004** of Figure **23A**) further includes traversing all of the physical transport layers in first communication pencil **400** (step of **1032** of Figure **23B**).

5   Third Node **500** (1,0) communicating with second Node **500** (1,1) via second communication pencil **310** (step of **1008** of Figure **23A**) further includes traversing all of the physical transport layers in second communication pencil **310** (step of **1052** of Figure **23C**).

A corresponding coupled communication pencil may include one of the
10   physical transport layers. At least one of the corresponding coupled communication pencils may include a first and a second of the physical transport layers.

By way of example, in communications systems employing communications pencils similar to Figure **3C** of the prior art discussion, the write optical fiber
15   from the nodes to the control point comprises the first physical transport, the traversal of the control point constitutes the traversal between the first and second physical transport layers, and traversal of the read optical fiber constitutes traversal of the second physical transport.

The physical transport layers of a communication pencil may include but are
20   not limited to a wave guide. The wave guide may physically transport at least in the microwave domain. The wave guide may physically transport at least in the infrared domain. The wave guide may physically transport at least in the optical domain. The wave guide may physically transport at least in the radio domain.

As used herein, a wave guide may include but is not limited to at least one optical fiber, at least one coaxial cable and/or at least one wire. Further, a physical transport layer may include but is not limited to at least one twisted pair of wires.

5 Note that certain embodiments of the invention may include redundant communication pencils coupled to a node pencil, redundant communication paths within a communication pencil, or redundant physical transport within a communication path, which may or may not involve distinct physical transport layers. The necessary physical transport layers included in a communication

10 will be understood to be those physical transport layers used to actually communicate between the relevant nodes.

Consider a node 500 coupling to M communication pencils, where M is at least two. The node 500 includes M communication interfaces 506, each communication interfaces coupling to a corresponding communication pencil.

15 In Figure 25, M will be assumed to be less than 6. This has been done for the sake of simplicity of discussion and is not meant to limit M in any way.

Figure 25 depicts a flowchart of a communication process performed within the node 500 controlling all of the M communications interfaces, where M is between 2 and 5, in accordance with certain embodiments of the invention.

20 Operation 1300 starts the operations of this flowchart. Arrow 1302 directs the flow of execution from operation 1300 to operation 1304. Operation 1304 performs interacting within the node with the first communication interface. Arrow 1306 directs execution from operation 1304 to operation 1308. Operation 1308 terminates the operations of this flowchart.

Arrow **1310** directs the flow of execution from starting operation **1300** to operation **1312**. Operation **1312** performs interacting within the node with the second communication interface. Arrow **1314** directs execution from operation **1312** to operation **1308**. Operation **1308** terminates the operations

5   of this flowchart.

Arrow **1320** directs the flow of execution from starting operation **1300** to operation **1322**. Operation **1322** performs interacting within the node with the third communication interface. Arrow **1324** directs execution from operation **1322** to operation **1308**. Operation **1308** terminates the operations of this

10 flowchart.

Arrow **1330** directs the flow of execution from starting operation **1300** to operation **1332**. Operation **1332** performs interacting within the node with the fourth communication interface. Arrow **1334** directs execution from operation **1332** to operation **1308**. Operation **1308** terminates the operations of this

15 flowchart.

Arrow **1340** directs the flow of execution from starting operation **1300** to operation **1342**. Operation **1342** performs interacting within the node with the fifth communication interface. Arrow **1344** directs execution from operation **1342** to operation **1308**. Operation **1308** terminates the operations of this

20 flowchart.

To further simplify the discussion, only operation **1304** will be expanded in subsequent flowcharts and their accompanying discussion. It is to be understood that any discussion of interaction within a node with one communication interface applies in all its variations to the interaction within a

67

node with a different communication interface, and that two communication interfaces may differ in how their interactions are embodied within a single node.

Figure **26** depicts a detail flowchart of operation **1304** of Figure **25** further performing interacting within the node with the first communication interface in accordance with certain embodiments of the invention.

Arrow **1370** directs the flow of execution from starting operation **1304** to operation **1372**. Operation **1372** performs receiving a first communication from the communication interface to create a received communication from the communication interface. Arrow **1374** directs execution from operation **1372** to operation **1376**. Operation **1376** terminates the operations of this flowchart.

Arrow **1380** directs the flow of execution from starting operation **1304** to operation **1382**. Operation **1382** performs processing the received communication from the communication interface. Arrow **1384** directs execution from operation **1382** to operation **1376**. Operation **1376** terminates the operations of this flowchart.

Arrow **1390** directs the flow of execution from starting operation **1304** to operation **1392**. Operation **1392** performs sending a local communication to the communication interface to create a second communication to the communication interface. Arrow **1394** directs execution from operation **1392** to operation **1376**. Operation **1376** terminates the operations of this flowchart.

A communication processor may be included within the node **500**, coupled to at least one communication interface.

Figure **27A** depicts a detail flowchart of operation **1372** of Figure **26** further performing for each of the communication interfaces coupled to the communication processor, receiving the first communication.

Arrow **1410** directs the flow of execution from starting operation **1372** to

5   operation **1412**. Operation **1412** performs the communication processor receiving the first communication from the communication interface to create the received communication from the communication interface. Arrow **1414** directs execution from operation **1412** to operation **1416**. Operation **1416** terminates the operations of this flowchart.

10   Figure **27B** depicts a detail flowchart of operation **1382** of Figure **26** further performing for each of the communication interfaces coupled to the communication processor, processing the received communication.

Arrow **1430** directs the flow of execution from starting operation **1382** to operation **1432**. Operation **1432** performs the communication processor

15   processing the received communication from the communication interface. Arrow **1434** directs execution from operation **1432** to operation **1436**. Operation **1436** terminates the operations of this flowchart.

Figure **27C** depicts a detail flowchart of operation **1392** of Figure **26** further performing for each of the communication interfaces coupled to the

20   communication processor, sending the local communication.

Arrow **1450** directs the flow of execution from starting operation **1392** to operation **1452**. Operation **1452** performs the communication processor sending the local communication to the communication interface to create the second communication to the communication interface. Arrow **1454** directs

execution from operation **1452** to operation **1456**. Operation **1456** terminates the operations of this flowchart.

Figure **28A** depicts a detail flowchart of operation **1432** of Figure **27B** further performing processing the received communication in accordance with certain
5 embodiments of the invention.

Arrow **1510** directs the flow of execution from starting operation **1432** to operation **1512**. Operation **1512** performs determining a received communication destination based upon the received communication from the communication interface. Arrow **1514** directs execution from operation **1512**
10 to operation **1516**. Operation **1516** terminates the operations of this flowchart.

Arrow **1520** directs the flow of execution from starting operation **1432** to operation **1522**. Operation **1522** performs routing the received communication whenever the received communication destination is external to the node. Arrow **1524** directs execution from operation **1522** to operation
15 **1516**. Operation **1516** terminates the operations of this flowchart.

Arrow **1530** directs the flow of execution from starting operation **1432** to operation **1532**. Operation **1532** performs delivering the received communication whenever the received communication destination is internal to the node. Arrow **1534** directs execution from operation **1532** to operation
20 **1516**. Operation **1516** terminates the operations of this flowchart.

Figure **28B** depicts an alternative detail flowchart of operation **1432** of Figure **27B** further performing processing the received communication in accordance with certain embodiments of the invention.

Arrow **1550** directs the flow of execution from starting operation **1432** to operation **1552**. Operation **1552** performs determining a received communication destination based upon the received communication from the communication interface. Arrow **1554** directs execution from operation **1552**

5   to operation **1556**. Operation **1556** performs routing the received communication whenever the received communication destination is external to the node. Arrow **1558** directs execution from operation **1556** to operation **1560**. Operation **1560** performs delivering the received communication whenever the received communication destination is internal to the node.

10   Arrow **1562** directs execution from operation **1560** to operation **1564**. Operation **1564** terminates the operations of this flowchart.

Note that Figures **28A** and **2 8 B** depict two of several organizational approaches to implementing very similar if not the same operations. Figure **28A** tends to be in keeping with many event triggered real time environments,

15   where each of the operations may be independently and concurrently performed, possibly with queuing mechanisms applied before or after performance of one or more of these operations. Figure **28B** tends to be in keeping with a determination of destination, sequentially followed by executing of one or both of the operations of routing and delivery. By way of

20   example, flowcharts could be drawn showing only one choice, to route or to deliver, which would be in accordance with certain other embodiments of the invention. However, for the sake of simplicity of discussion, only Figures **28A** and **28B** have been provided.

In the following discussion, only operation **1512** will be referenced for determining based upon the received communication. This is not intended to limit the scope of invention in any way, but to simplify the discussion.

Figure **29A** depicts a detail flowchart of operation **1512** of Figure **28A** further performing determining the received communication destination.

Arrow **1570** directs the flow of execution from starting operation **1512** to operation **1572**. Operation **1572** performs extracting from the received communication to create a destination component. Arrow **1574** directs execution from operation **1572** to operation **1576**. Operation **1576** terminates the operations of this flowchart.

Arrow **1580** directs the flow of execution from starting operation **1512** to operation **1582**. Operation **1582** performs evaluating the destination component to create the received communication destination. Arrow **1584** directs execution from operation **1582** to operation **1576**. Operation **1576** terminates the operations of this flowchart.

Figure **29B** depicts an alternative detail flowchart of operation **1512** of Figure **28A** further performing determining the received communication destination in accordance with certain embodiments of the invention.

Arrow **1590** directs the flow of execution from starting operation **1512** to operation **1592**. Operation **1592** performs extracting from the received communication to create a destination component. Arrow **1594** directs execution from operation **1592** to operation **1596**. Operation **1596** performs evaluating the destination component to create the received communication

destination. Arrow **1598** directs execution from operation **1596** to operation **1600**. Operation **1600** terminates the operations of this flowchart.

Note that Figures **29A** and **29B** depict two of several organizational approaches to implementing very similar if not the same operations. Figure **29A** tends to be in keeping with many event triggered real time environments, where each of the operations may be independently and concurrently performed, possibly with queuing mechanisms applied before or after performance of one or more of these operations. Figure **29B** tends to be in keeping with a determination of destination, sequentially followed by executing of one or both of the operations of routing and delivery.

In the following discussion, only operation **1572** will be referenced for extracting from the received communication to create a destination component. This is not intended to limit the scope of invention in any way, but to simplify the discussion.

In the following discussion, only operation **1582** will be referenced for evaluating the destination component to create the received communication destination. This is not intended to limit the scope of invention in any way, but to simplify the discussion.

Figure **30A** depicts a detail flowchart of operation **1300** of Figure **25** further performing the communication process within the node.

Arrow **1610** directs the flow of execution from starting operation **1300** to operation **1612**. Operation **1612** performs maintaining a routing table. Arrow **1614** directs execution from operation **1612** to operation **1616**. Operation **1616** terminates the operations of this flowchart.

73

Figure **30B** depicts a detail flowchart of operation **1582** of Figure **29A** further performing evaluating the destination component.

Arrow **1630** directs the flow of execution from starting operation **1582** to operation **1632**. Operation **1632** performs examining the routing table based

5   upon the destination component to create the received communication destination. Arrow **1634** directs execution from operation **1632** to operation **1636**. Operation **1636** terminates the operations of this flowchart.

The communication processor may further couple to each of the communication interfaces.

10 Alternatively, there may be P communication processors, where P is at least two. Each communication processor couples to at least one communication interface and each communication interface couples to at least one communication processor. For each of the communication processors, and each communication interface coupled to the communication, the

15 communication processor performs the operations found in Figures **27A-27C**. The subsequent operations discussed in Figures **28A** to **30B** may be further performed by one or more of the communication processors.

The node **500** may further include a communication processor coupling mechanism coupling at least two of the communication processors.

20 Figure **31A** depicts a detail flowchart of operation **1522** of Figure **29A** further performing routing the received communication for a communication processor coupled to the communication processor coupling mechanism.

Arrow **1630** directs the flow of execution from starting operation **1522** to operation **1632**. Operation **1632** performs routing the received communication based upon the communication processor coupling mechanism whenever the received communication destination is external to

5 the node. Arrow **1634** directs execution from operation **1632** to operation **1636**. Operation **1636** terminates the operations of this flowchart.

Note that in certain embodiments of the invention, operation **1632** takes into account the communication processor coupling mechanism, but may not actively use that mechanism.

10 The node **500** may include a second communication processor coupling mechanism coupling at least two of the communication processors.

Figure **31B** depicts a detail flowchart of operation **1522** of Figure **29A** further performing for each of the communication processors, routing the received communication.

15 Arrow **1650** directs the flow of execution from starting operation **1522** to operation **1652**. Operation **1652** performs routing the received communication based upon the communication processor coupling mechanism and based upon the second communication processor coupling mechanism whenever the received communication destination is external to

20 the node. Arrow **1654** directs execution from operation **1652** to operation **1656**. Operation **1656** terminates the operations of this flowchart.

Figure **31C** depicts a detail flowchart of operation **1532** of Figure **28A** further performing for each of the communication processors, delivering the received communication.

75

Arrow **1670** directs the flow of execution from starting operation **1532** to operation **1672**. Operation **1672** performs delivering the received communication based upon the communication processor coupling mechanism whenever the received communication destination is internal to the node. Arrow **1674** directs execution from operation **1672** to operation **1676**. Operation **1676** terminates the operations of this flowchart.

Figure **32A** depicts a detail flowchart of operation **1532** of Figure **28A** further performing for each of the communication processors, the step of delivering the received communication.

Arrow **1690** directs the flow of execution from starting operation **1532** to operation **1692**. Operation **1692** performs routing-elsewhere the received communication based upon the communication processor coupling mechanism whenever the received communication destination is internal to the node and the received communication destination is not coupled to the communication processor coupling mechanism. Arrow **1694** directs execution from operation **1692** to operation **1696**. Operation **1696** terminates the operations of this flowchart.

Note that node **500** may include the communication processor coupling mechanism comprising a bus coupling at least two of the communication processors coupled by the communication processor coupling mechanism. The communication processor coupling mechanism may include a bus coupling all of the communication processors coupled by the communication processor coupling mechanism. The communication processor coupling mechanism may include a bus coupling all of the communication processors.

In certain embodiments of the invention, failures within node **500** may in effect create two (or more) communication coupling mechanisms. The above discussion of two communication coupling mechanisms may be extended to more than two communication coupling mechanisms in keeping with certain
5   further embodiments of the invention.

A communication processor may be accessibly coupled to the routing table. The communication processor may include a finite state machine at least partially controlled by a control register based upon accessing the routing table.

10   The communication processor may include an instruction processor accessibly coupled to a memory. A program system may reside in the accessibly coupled memory comprised of at least the program step of processing the received communication from the communication interface, for a communication interface coupled to the communication processor as shown
15   in operation **1432** of Figure **27B**. Note that either of the other operations of Figure **27A** and **27C** may or may not be part of the program system residing in the accessibly coupled memory of the communication processor.

The program step of **1432** of the program system residing in the accessibly coupled memory of the communication processor

20   Figure **32B** depicts a detail flowchart of operation **1432** of Figure **27B** further performing processing the received communication from the communication interface coupled to the communication processor.

Arrow **1710** directs the flow of execution from starting operation **1432** to operation **1712**. Operation **1712** performs determining based upon the

77

received communication from the communication interface to create a received communication destination. Arrow **1714** directs execution from operation **1712** to operation **1716**. Operation **1716** terminates the operations of this flowchart.

5   Arrow **1720** directs the flow of execution from starting operation **1432** to operation **1722**. Operation **1722** performs routing the received communication whenever the received communication destination is external to the node. Arrow **1724** directs execution from operation **1722** to operation **1716**. Operation **1716** terminates the operations of this flowchart.

· 10   Arrow **1730** directs the flow of execution from starting operation **1432** to operation **1732**. Operation **1732** performs delivering the received communication whenever the received communication destination is internal to the node. Arrow **1734** directs execution from operation **1732** to operation **1716**. Operation **1716** terminates the operations of this flowchart.

15   Figure **33A** depicts a detail flowchart of operation **1712** of Figure **32B** further performing determining based upon the received communication from the communication interface.

Arrow **1750** directs the flow of execution from starting operation **1712** to operation **1752**. Operation **1752** performs evaluating the destination
20   component to create the received communication destination. Arrow **1754** directs execution from operation **1752** to operation **1756**. Operation **1756** terminates the operations of this flowchart.

Figure **33B** depicts a detail flowchart of operation **1612** of Figure **30A** further performing maintaining the routing table.

Arrow **1770** directs the flow of execution from starting operation **1612** to operation **1772**. Operation **1772** performs generating a new routing table. Arrow **1774** directs execution from operation **1772** to operation **1776**. Operation **1776** terminates the operations of this flowchart.

5   Arrow **1780** directs the flow of execution from starting operation **1612** to operation **1782**. Operation **1782** performs distributing the new routing table to replace the routing table. Arrow **1784** directs execution from operation **1782** to operation **1776**. Operation **1776** terminates the operations of this flowchart.

Figure **34A** depicts a detail flowchart of operation **1782** of Figure **33B** further
10   performing distributing the new routing table.

Arrow **1790** directs the flow of execution from starting operation **1782** to operation **1792**. Operation **1792** performs communicating the new routing table. Arrow **1794** directs execution from operation **1792** to operation **1796**. Operation **1796** terminates the operations of this flowchart.

15   Arrow **1800** directs the flow of execution from starting operation **1782** to operation **1802**. Operation **1802** performs replacing the routing table with the new routing table. Arrow **1804** directs execution from operation **1802** to operation **1796**. Operation **1796** terminates the operations of this flowchart.

Figure **34B** depicts a detail flowchart of operation **1792** of Figure **34A** further
20   performing communicating the new routing table.

Arrow **1810** directs the flow of execution from starting operation **1792** to operation **1812**. Operation **1812** performs transmitting the new routing table via each of the communication interfaces to create a new transmitted routing

table. Arrow **1814** directs execution from operation **1812** to operation **1816**. Operation **1816** terminates the operations of this flowchart.

Arrow **1820** directs the flow of execution from starting operation **1792** to operation **1822**. Operation **1822** performs receiving the new transmitted

5   routing table to create the new routing table. Arrow **1824** directs execution from operation **1822** to operation **1816**. Operation **1816** terminates the operations of this flowchart.

Figure **35A** depicts a detail flowchart of operation **1802** of Figure **34A** further performing replacing the routing table.

10   Arrow **1830** directs the flow of execution from starting operation **1802** to operation **1832**. Operation **1832** performs generating a local routing table from the new routing table. Arrow **1834** directs execution from operation **1832** to operation **1836**. Operation **1836** terminates the operations of this flowchart.

Arrow **1840** directs the flow of execution from starting operation **1802** to

15   operation **1842**. Operation **1842** performs exchanging the routing table with the local routing table. Arrow **1844** directs execution from operation **1842** to operation **1836**. Operation **1836** terminates the operations of this flowchart.

Figure **35B** depicts a detail flowchart of operation **1772** of Figure **33B** further performing generating the new routing table.

20   Arrow **1850** directs the flow of execution from starting operation **1772** to operation **1852**. Operation **1852** performs maintaining a network map. Arrow **1854** directs execution from operation **1852** to operation **1856**. Operation **1856** terminates the operations of this flowchart.

Arrow **1860** directs the flow of execution from starting operation **1772** to operation **1862**. Operation **1862** performs assessing the network map to create an obstruction map. Arrow **1864** directs execution from operation **1862** to operation **1856**. Operation **1856** terminates the operations of this flowchart.

5   Arrow **1870** directs the flow of execution from starting operation **1772** to operation **1872**. Operation **1872** performs optimizing the network map based upon the obstruction map to create the new routing table. Arrow **1874** directs execution from operation **1872** to operation **1856**. Operation **1856** terminates the operations of this flowchart.

10   Note that for certain nodes **500**, at least one instruction processor may be coupled to the communication processor.

Figure **36A** depicts a detail flowchart of operation **1532** of Figure **28A** further performing delivering the received communication.

Arrow **1890** directs the flow of execution from starting operation **1532** to
15   operation **1892**. Operation **1892** performs delivering to the instruction processor the received communication whenever the received communication destination targets the instruction processor. Arrow **1894** directs execution from operation **1892** to operation **1896**. Operation **1896** terminates the operations of this flowchart.

20   A node **500** may include a communication processor coupled to a second instruction processor.

Figure **36B** depicts a detail flowchart of operation **1532** of Figure **28A** further performing delivering the received communication.

Arrow **1910** directs the flow of execution from starting operation **1532** to operation **1912**. Operation **1912** performs delivering to the second instruction processor the received communication whenever the received communication destination targets the second instruction processor. Arrow **1914** directs

5   execution from operation **1912** to operation **1916**. Operation **1916** terminates the operations of this flowchart.

Figure **36C** depicts a detail flowchart of operation **1382** of Figure **26** further performing processing the received communication.

Arrow **1930** directs the flow of execution from starting operation **1382** to

10   operation **1932**. Operation **1932** performs assessing the received communication from the communication interface to create a next communication activity. Arrow **1934** directs execution from operation **1932** to operation **1936**. Operation **1936** performs activating the next communication activity based upon the received communication. Arrow **1938** directs

15   execution from operation **1936** to operation **1940**. Operation **1940** terminates the operations of this flowchart.

Figure **37A** depicts a detail flowchart of operation **1932** of Figure **36C** further performing assessing the received communication.

Arrow **1950** directs the flow of execution from starting operation **1932** to

20   operation **1952**. Operation **1952** performs extracting from the received communication to create a destination component. Arrow **1954** directs execution from operation **1952** to operation **1956**. Operation **1956** terminates the operations of this flowchart.

82

Arrow **1960** directs the flow of execution from starting operation **1932** to operation **1962**. Operation **1962** performs evaluating the destination component to create the next communication activity. Arrow **1964** directs execution from operation **1962** to operation **1956**. Operation **1956** terminates

5   the operations of this flowchart.

Figure **37B** depicts an alternative detail flowchart of operation **1932** of Figure **36C** further performing assessing the received communication.

Arrow **1970** directs the flow of execution from starting operation **1932** to operation **1972**. Operation **1972** performs extracting from the received

10 communication to create a destination component. Arrow **1974** directs execution from operation **1972** to operation **1976**. Operation **1976** performs evaluating the destination component to create the next communication activity. Arrow **1978** directs execution from operation **1976** to operation **1980**. Operation **1980** terminates the operations of this flowchart.

15 Note that Figures **37A** and **3 7 B** depict two of several organizational approaches to implementing very similar if not the same operations, both in accordance with certain embodiments of the invention. Figure **37A** tends to be in keeping with many event triggered real time environments, where each of the operations may be independently and concurrently performed, possibly

20 with queuing mechanisms applied before or after performance of one or more of these operations. Figure **37B** tends to be in keeping with extracting a destination component, sequentially followed by evaluating the destination component to create a next communication activity.

A node **500** may include a tunnel interface coupling to the node. The node communication process may include steps similar to the steps for interaction with a communication interface. The node **500** may include a communication processor coupled to the tunnel interface. A communication processor within

5   the node **500** may further interact with tunnel interface in a similar manner to the interaction of the communication processor with a coupled communication interface. The interaction may be at least in part implemented as part of a program system residing in an accessibly coupled memory of an instruction processor coupled to the communication processor.

10   A communication interface within a node may include one or more ports. These ports may be used for transmitting or receiving communications within the communication pencil, or for both transmitting and receiving communications. Distinct ports within a communication interface may employ the same physical transport or distinct physical transports. The node

15   communication process may include steps similar to the steps for interaction with a communication interface. The node **500** may include a communication processor coupled to one or more ports. A communication processor within the node **500** may further interact with ports in a similar manner to the interaction of the communication processor with a coupled communication

20   interface. The interaction may be implemented as part of a program system residing in an accessibly coupled memory of an instruction processor coupled to the communication processor.

Figure **38** depicts a communication interface **900** including P1=4 input ports and P2=4 output ports coupled to a communication pencil including optical

25   fibers **902** and **904**, each optical fiber handling one way traffic with optical

fiber **902** coupled **940** through optronic amplifier **942** coupling **944** to optical

fiber **904**, in accordance with certain embodiments of the invention.

As used herein optronic refers to devices, technologies and communications

protocols which may include some or all of the visible light or near visible light

5   spectrum. Infra-red and ultraviolet spectral ranges will be considered as part

of the near visible light spectrum.

As used herein, optronic amplifier **942** may include a splitter feeding multiple

optronic signals, each optronic signal being band pass filtered to a color

component signal, each color component signal being separately amplified,

10   then combined to create the optronic signal injected **944** to optical cable **904**.

The separate amplification of each color component signal may further

include separate gain controls providing different color component signal gain

across the respective color component signal amplifiers. The separate

amplification of each color component signal may also include splitting the

15   color component signal to create multiple split color signals, filtering each of

the split color signals, separate amplification of the filtered, split color signals,

which are then combined to form the amplified color component signal.

The P2=4 output ports **930-936** control a circuit which couples **906** to output

optical fiber **902**. Note that P2 may be 1. P2 may be greater than 1. P2 may

20   be greater than 4. The discussion is presented with P2=4 to both

demonstrate the scalability of the communication interface in terms of output

ports and to constrain the complexity of the discussion.

The P1=4 input ports **958**, **968**, **978** and **988** are driven from a circuit coupled

946 to input optical fiber **904**. Note that P1 may be 1. P1 may be greater than

85

1. P1 may be greater than 4. The discussion is presented with P1=4 to both demonstrate the scalability of the communication interface in terms of input ports and to constrain the complexity of the discussion.

Output port **930** controls optronic source **910** generating optronic signal **912**.

5   Output port **932** controls optronic source **914** generating optronic signal **916**. Output port **934** controls optronic source **918** generating optronic signal **920**. Output port **936** controls optronic source **922** generating optronic signal **924**.

Optronic signals **912**, **916**, **920** and **924** are presented to combiner **908** to create a combined optronic signal coupled **906** to output optical fiber **902**.

10   Coupling **906** to output optical fiber **902** may include injection of the combined optronic signal at a bend in optical fiber **902**. Coupling **906** to output optical fiber **902** may further include injection of the combined optronic signal at a bend in optical fiber **902** through an optronic amplifier. The optronic amplifier may include gain controls.

15   Input optical fiber **904** couples **946** to splitter **948** to generate optronic signals **950**, **960**, **970**, and **980**. Optronic signal **950** feeds filter **952** to create optronic color signal **954** which stimulates optronic detector **956**. Optronic detector **956** drives the state of port **958**. Optronic signal **960** feeds filter **962** to create optronic color signal **964** which stimulates optronic detector **966**. Optronic

20   detector **966** drives the state of port **968**. Optronic signal **970** feeds filter **972** to create optronic color signal **974** which stimulates optronic detector **976**. Optronic detector **976** drives the state of port **978**. Optronic signal **980** feeds filter **982** to create optronic color signal **984** which stimulates optronic detector **986**. Optronic detector **986** drives the state of port **988**.

Coupling **946** between output optical fiber **904** and splitter **948** may include a receptor positioned at a bend in optical fiber **904**. Coupling **946** from output optical fiber **904** may further include the receptor containing an optronic amplifier positioned at the bend in optical fiber **904** to generate the optronic

5   signal presented to splitter **948**. The optronic amplifier may include gain controls.

The preceding embodiments have been provided by way of example and are not meant to constrain the scope of the following claims.

Claims

1.   A communications network with M orthogonal directions supporting

communications between an M dimensional lattice of a multiplicity of nodes

5   each containing a multiplicity of ports, said communications network

comprising:

a communication grid interconnecting said nodes, said grid further

comprising:

a multiplicity of communication pencils, for each of said M orthogonal

10   directions;

wherein each of said communication pencils in each orthogonal

direction is coupled with a corresponding node pencil containing a multiplicity

of nodes to couple each of said nodes of said corresponding node pencil

directly to the other nodes of said corresponding node pencil;

15   wherein M is at least two; and

wherein the number of nodes in each of said node pencils in a first of

said orthogonal directions is at least four;

wherein the number of nodes in each of said node pencils in a second

of said orthogonal directions is at least two.

20   2.   The communications network of Claim 1,

wherein the number of nodes in each of said node pencils in said

second orthogonal direction is at least three.

3.   The communications network of Claim 2,

wherein the number of nodes in each of said node pencils in said

25   second orthogonal direction is at least four.